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Crop water productivity (CWP) with the small farm reservoir (SFR) as a supplemental irrigation for cash crop on rainfed area in Karanganyar Regency, Indonesia

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Precipitation patterns have changed due to climate change, consequently lead to frequent short drought in Karanganyar Regency, Indonesia. Small farm reservoir (SFR) is one of the water harvesting methods on farm lands, and the harvested water can be used for supplemental irrigation (SI) during dry season. The purposes of the research are to determine the efficiency and sufficiency of irrigation water based on crop evapotranspiration (ETc); and crop water productivity (CWP) of cash crop (paddy, chili, sweet corn). CWP was calculated by dividing the actual crop production (kg/ha) by the total number of irrigation water (mm). The experiment included five treatments of irrigation levels (0. 25. 50. 75. and 100% ETc) with five replications. Data analysis used Fisher Test (F-test) 5%, followed with Duncan Multiple Range Test 5%, when the F-test showed significant different. The results showed that water from SFR was estimated to be sufficient but inefficient due to water loss 1.9 higher than the total needs during two cropping seasons (14.544 m^3). Supplemental irrigation did not affect the CWP, when rainfall was adequate.

Keywords: short drought, small farm reservoir, supplemental irrigation, crop evapotranspiration, crop water productivity

INTRODUCTION

Indonesia consists of nearly two million square km of land and lays on the equator. Indonesia is vulnerable to climate change, because precipitation patterns have changed and impacted agriculture due to climate change (BPPP, 2011). For example, particularly in Central Java, the volume and rain interval change (Pramudia, 2006); (Komariah and Sumani, 2011), which lead to uncertainty in producing consistent agricultural goods due to short drought. Whereas during rainy season, approximately 50-200 mm rainwater is thrown away as runoff or deep percolation every month, because exceeded its soil-water holding capacity (Komariah et al., 2010). This condition can be overcame by harvesting rainfall in a small farm reservoir (SFR) like a pond (BPTP, 1997).

Water in SFR can be reused for supplemental irrigation and increase agricultural economic production at Filipina (Guerra et al., 1990), India (Paul and Tiwari, 1994) and Indonesia (Syamsiah et al., 1994) or early dry season

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(Panigrahi et al., 2005). However, there are constraints in the utilization of SFR water, specifically during dry season when the imbalance of the inflow and outflow occurs. This paper aimed at determining the efficiency and sufficiency of irrigation water according to crop water requirement (ETc) and crop water productivity (CWP) of cash crop (paddy, chili, sweet corn). CWP was calculated by dividing the actual crop production (kg/ha) with the number of irrigation water given (mm) (Molden, 1997). It is expected that the recommendation resulted from this research will be contribute for farmers, especially on lower the crop failure events due to shortdrought, and increasing farmers income with cash crop cultivation.

MATERIALS AND METHODS

The experiment was an on-farm experiment and conducted for two growing seasons: April-August 2013; and August-December 2013. The experimental plots were setted up in the surrounding of a small farm reservoir (SFR) in Gondangrejo district, Karanganyar regency (latitude 7^{o} 29' S dan longitude 110^{o} 51' E). Weather components were observed with portable weather station Davis Vintage Pro2®, which recorded weather components data every 10 minutes. Laboratory analysis was carried out in Faculty of Agriculture, Sebelas Maret University, Indonesia.

The materials are seeds, fertilizers (organic and anorganic fertilizer), pesticide and insecticide, fuel for water pump, and chemical for laboratory analysis. The seeds are included paddy (*Oryza sativa* L. var *situ bagendit*), chili (*Capsicum frutescens* L.), and sweet corn (*Zea mays* L. var. *saccharata* (Sturtev.). The experiment was arranged in Randomized Complete Block Design with five treatments of irigation volume, i.e: 0. 25; 0.50; 0.75; and 1 of crop evapotranspiration (ETc), with five replications. At the beginning, plots were prepared by creating the bunds with the size of (4×1.6) m^2 for paddy and chili, and (3×1.5) m^2 for sweet corn, the distance between each bund was 50 cm. Then the soil at each bund was mixed with organic fertilizer (cow manure compost), with the dose of 5 ton/ha. The plant spacing were 40cm×20cm×10cm (*Legowo* system) for paddy; 50x40 cm Transplanting the seeds to the field was carried out during 100 day with a spacing of, chili was 120 day with a spacing of, and sweet corn was 80 day with a spacing of 25×50 cm.

Nitrogen (N), Phosphate (P_2O_5), and Potassium Oxide (K_2O) were applied for fertilizer. The application of N: P_2O_5:K_2O ratio are 200:200:150 for paddy, (Permentan, 2007); 200:200:150 for chili (Setyawati et al., 2007); and 300:75:75 for sweet corn (PTP, 2007). Supplemental irrigation was applied based on crop evapotranspiration (ETc, where ETc = ETo x Kc; ETo= potential evapotranspiration; Kc= crop coefficient). the 2000-2010 ETo from April to December 2013 in the research site were 3.69; 3.56; 3.51; 3.66; 4.24; 4.75; 4.55; 4.08; 3.39 mm/day, respectively, using Penman-Monteith method with Cropwat 8.0 software (FAO, 2008). Kc of initial, mid and end of growth stages are 1.05; 1.20; 0.9 for paddy; 0.60; 1.05; 0.9 for chili, and 0.70; 1.15; 1.05 for sweet corn, respectively (FAO, 1998).

Data analysis used Fisher Test (F-test) 5%, followed with Duncan Multiple Range Test 5%, when the F-test showed significant different, then Pearson's correlation test. The observed parameters were climate variables (air temperature, relative humidity, solar radiation, and evapotranspiration); soil variables (total N, available soil P, exchange soil K, texture, permanent wilting point (PWP), and field capacity (FC); product, biomass and crop water productivity (CWP). CWP is determined by calculate the ratio of yield or biomass to total water given for irrigation.

RESULT AND DISCUSSION

1. Water Efficiency and Sufficiency

Small farm reservoir (SFR) serves as a reservoir of runoff from cacthment area with the size of 10 m length; 3 m width; and 2 m depth, thus the water capacity is approx. 60 m^3. SFR was lined with 3mm plastic sheet to reduce seepage. Collected water in the SFR then pumped out as supplemental irrigation (SI) for paddy, chili, and sweet corn. Total water requirement and water sufficiency from SFR are presented in table 1.

The irrigation water requirement for all crops for growing season 1 and 2 are presented in table 1. The total population of paddy, chili and sweet corn in each treatment were 2,100 (each plot size: 160 m^2 area); 600 (each plot size: 160 m^2); and sweet corn is 1,200 (each plot size: 112,5 m^2), respectively. Average water evaporation from SFR over two growing seasons was 3.82 mm/day; or total of 27.504 m^3 within 240 days during experimental.

Water in SFR was sufficient for both growing seasons 1 and 2 for all crops, but SFR was not efficient because the actual water loss (16.422 m^3) was 1.9 greater compared to total water usage (6.378 m^3) for irrigation as presented in table 1, In other words, 27.37% (table 2) of water in SFR lost due to evaporation or seepage, because the plastic sheet might be little broken. However, the water loss from SFR in this research was lower than SFR in the research conducted by Syamsiah et. al. (1994), while 65% water from SFR lost due to evaporation, seepage, and percolation. It is suggested for further research to plant trees with broad leaves surrounding the SFR, or cover the SFR with dark thin nets to reduce evaporation.

Table 1. Total water requirement and water sufficiency from SFR

No	Crop	Cropping period (days)	Total water requirement (m^3)		SFR capacity (m^3)	Evaporation		Remained water in SFR (m^3)
			Season 1	Season 2		rate (mm/ day)	SFR total (m^3)	
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*
1	Paddy	100 x 2	5.147	6.634				
2	Chili	120 x 2	0.653	0.791				
3	Sweet corn	80 x 2	0.577	0.752	60.0	3.82	27.50	17.94
Sub total for 1 season			6.378	8.176				
Total for 2 seasons			14.54					

Notes: (*g*) = calculation using *Penman-Monteith* of 2000-2010 climate data with Cropwat 8.0
(*h*) = SFR surface area (30 m^2) × the longest period of (*c*) × (*g*)
(*i*) = (*f*) – (*d*+*e*) – (*h*)

Table 2. Actual SFR water loss (during season 1)

SFR volume at initial	Total water usage	SFR volume at final	Actual water loss in SFR	
(m^3)	(m^3)	(m^3)	(m^3)	%
60	6.378	37.200	16.422	27.37

2. Weather Conditions

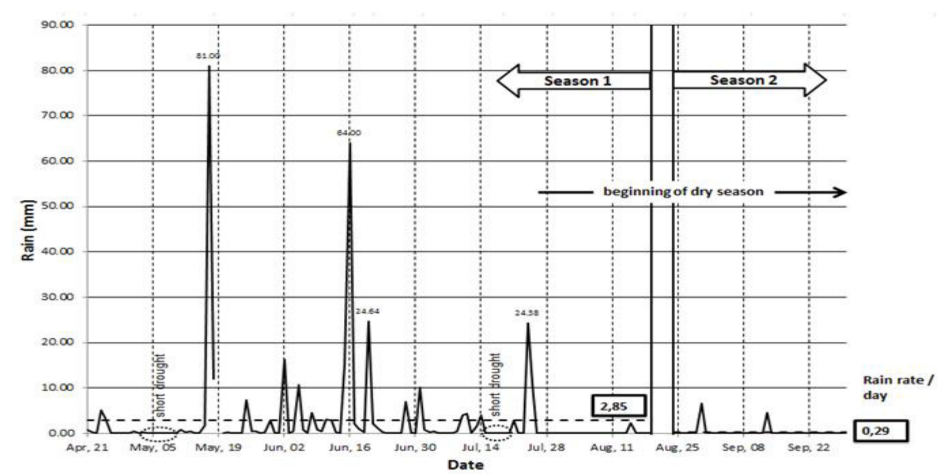
Weather conditions as the parameter of environment characteristics are rainfall, air temperature, relatif humidity, solar radiation, and evapotranspiration of both season 1 and 2. The results of the weather conditions presented in figure 1.

During the growing season 1, the number of rainy days were 51 days with total rainfall 341.77 mm. Meanwhile, the total rainy days were only 2 days with the total rainfall was only 11.16 mm during growing season 2. Short drought, or break season (no rain) occurred for 7 days (on May 4-10, 2013) at the beginning of the growing season 1; 6 days (July 15-20, 2013) at the end of season 1. In the area with the monsoon climate type such as Indonesia, the rainy season usually occurs in November-April. But the precipitation pattern has changed since the last few decades in several areas in Indonesia (BPPP, 2011), which caused the intensity of monthly precipitation tends to diver with higher deviations. Besides, the occurrence of extreme weather events is more frequent.

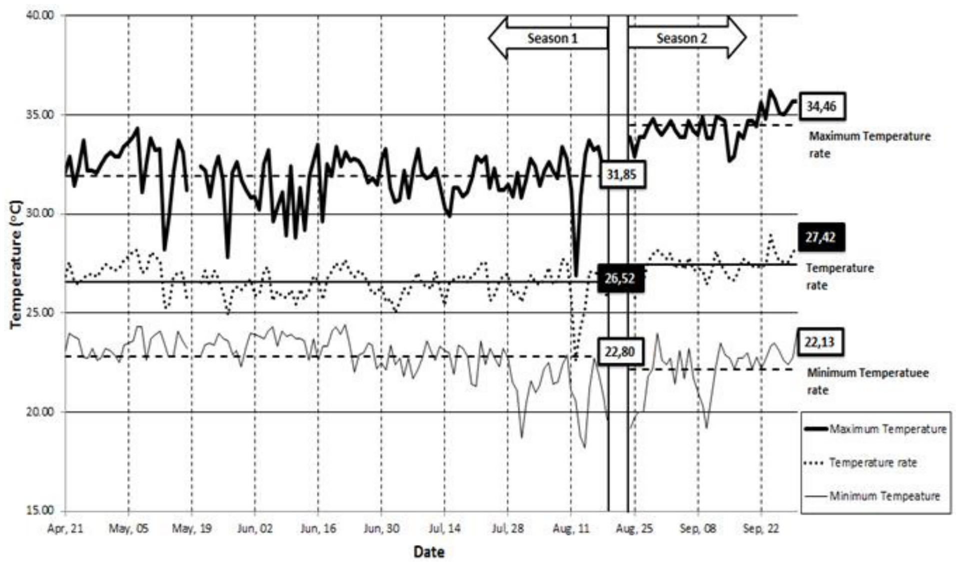
The daily air temperature at season 1 was lower than season 2 as shown in figure 1(b). The mean air temperature in season 2 was 0.89°C higher than season 1, while mean maximum air temperature in season 2 was 2.61°C higher than season 1, but the mean minimum air temperature was 0.67°C. Solar radiations at season 1 ranged 135.14 - 454.18 W/m^2 (mean 344.93 W/m^2), whereas solar radiation at season 2 ranged 364.62 - 500.92 W/m^2 (mean 453.07 W/m^2), or 108.14 W/m^2 higher. Hulme and Sheard (1999) cit. Case et al. (2007) observed that temperature in Indonesia from 1990 to 1999 increased about 0.3°C, with decline in annual rainfall of about 2-3%. The temperature increase was impacted by the precipitation pattern, which also leads to short drought/ break season increasing and the decline in available water. Therefore, the crop failure risk increase due to short drought/ break season because lack of water.

Figure 1 also shows that Relative humidity (RH) of season 2 was 15.67% lower than season 1, thus the air became more dry. This corresponded to the air temperature increased (correlation regression, r = -0.45), solar radiation increased (r = -0.83), and also evapotranspiration increased (r = -0.91). Low RH, high evapotranspiration (Spomer and Tibbitts, 1997), and high solar radiation (Sager and Farlane, 1997), causing the air become dry so that the water in plant depopulate faster as rising transpiration. Then the cells of plants begin to wither as dead, and if this goes on the eating of plants will die.

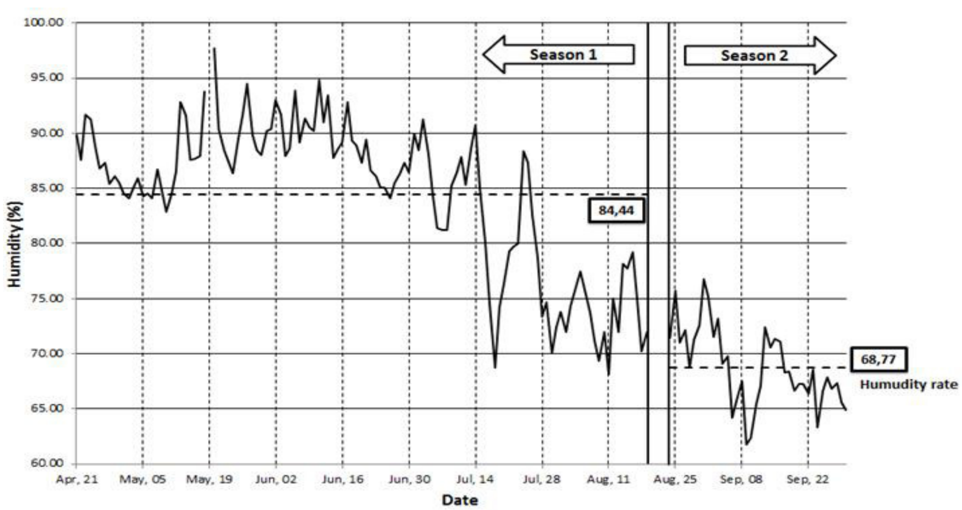
Based on weather analysis, the cultivation of all crops (paddy, chili, sweet corn) on season 1 is rather impossible, but impossible in season 2. Although water volume in SFR is estimated to be sufficient during cropping period of season 2, but air temperature, relative humidity, solar radiation, and potential evapotranspiration rate were not suitable for crops. According to land suitability (Djaenudin et al., 2011), the conditions of daily temperature of season 1 was very suitable for paddy, but the maximum daily temperature of season 2 was not suitable for paddy. For chili and sweet corn, the daily temperatures of season 2 were rather suitable, but maximum daily temperatures were not suitable. Because of those conditions, the experiment could not be continued in season 2 due to the crops wilting, and thus the discussion of soil and plant paramaters will be only focused on the results of season 1.


Rain (mm)
Date
Season 1
Season 2
beginning of dry season
short drought
short drought
81.00
64.00
24.64
24.58
2,85
0,29
Rain rate / day
Apr, 21
May, 05
May, 19
Jun, 02
Jun, 16
Jun, 30
Jul, 14
Jul, 28
Aug, 11
Aug, 25
Sep, 08
Sep, 22

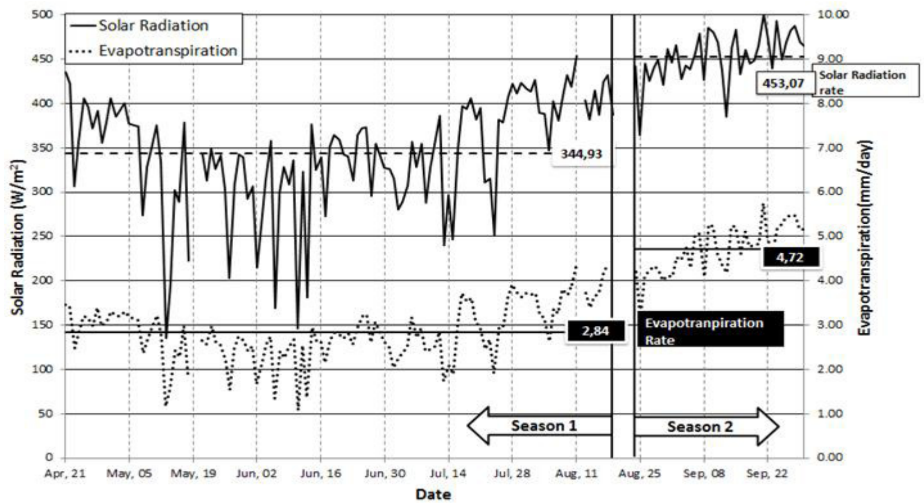
(a)


Temperature (°C)
Date
Season 1
Season 2
34,46
Maximum Temperature rate
31,85
27,42
Temperature rate
26,52
22,80
22,13
Minimum Temperatuee rate
Maximum Temperature
Temperature rate
Minimum Tempeature
Apr, 21
May, 05
May, 19
Jun, 02
Jun, 16
Jun, 30
Jul, 14
Jul, 28
Aug, 11
Aug, 25
Sep, 08
Sep, 22

(b)


Humidity (%)
Date
Season 1
Season 2
84,44
68,77
Humudity rate
Apr, 21
May, 05
May, 19
Jun, 02
Jun, 16
Jun, 30
Jul, 14
Jul, 28
Aug, 11
Aug, 25
Sep, 08
Sep, 22

(c)



(d)

Figure 1. Weather conditions of rainfall (a); air temperature (b); relative humidity (c); solar radiation and evapotranspiration (d)

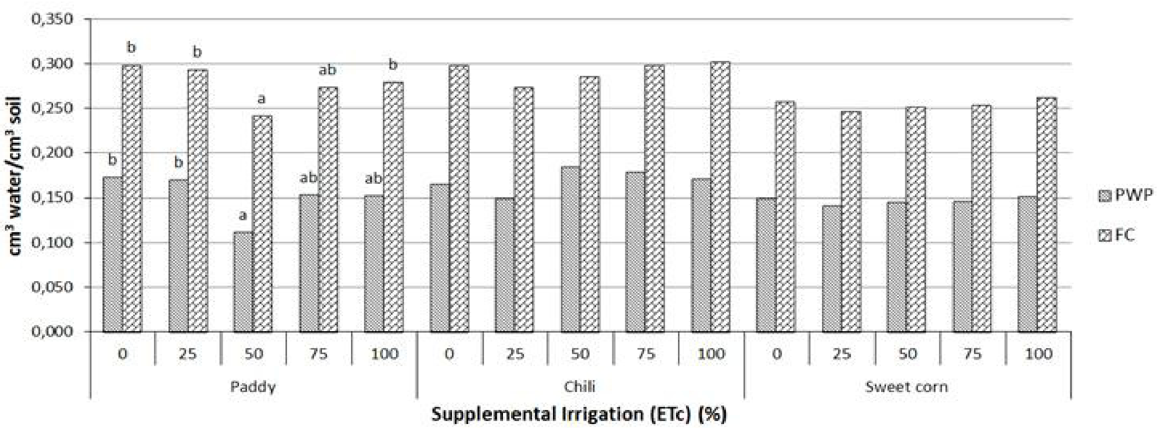


Figure 2. Soil PWP and FC characteristics

3. Soil Characteristic

Soil characteristics observed are soil permanent wilting point (PWP) and field capacity (FC), the results are as presented in figure 2. Supplemental irrigation (SI) treatments effected non significant differences on soil field capacity and permanent wilting point in chili and sweet corn plots (figure 2), but significantly different on paddy. That is probably because of the soil texture composition in paddy 50% ETc treatment was coincidently very different with others. It is predicted that there were no significant changes in soil physical properties, included PWP and FC in very short experimental period (3 months), because changes in soil physical characters takes long period sometimes more than 10 years. The results of soil macro nutrients included total nitrogen, available phosphate, and exchange potassium are presented in table 3. It is shown that there are no significant differences of total nitrogen in all treatments of all crops. Similar results are also shown in Potassium contents, where they are insignificantly differences at all treatments.

Table 3 shows that the phosphate contents in soil are not significantly different in all irrigation treatments in paddy and chili, but significantly different in sweet corn's irrigation treatments. Significantly high available phosphate in 25% ETc of irrigation treatments of sweet corn is probably because available phosphate had not absorbed by plants. Those are because the source of nutrients for all crops were derived from the same fertilizer, especially nitrogen is also derived from soil organic matter, micro-organisms, air, fertilization and rain (Hardjowigeno, 2007).

Table 3. Soil macro nutrient

Treatment	Nitrogen (%)			Phosphat (P_2O_5) (ppm)			Pottasium (K_2O) (cmol (+) kg^{-1})		
	Paddy	Chili	Sweet corn	Paddy	Chili	Sweet corn	Paddy	Chili	Sweet corn
0% ETc	0.13	0.13	0.10	12.26	23.46	2.84 a	0.15	0.83	0.41
25% ETc	0.15	0.10	0.09	14.67	22.65	5.87 c	0.21	0.77	0.30
50% ETc	0.13	0.12	0.12	15.81	27.81	3.49 ab	0.18	0.69	0.35
75% ETc	0.12	0.10	0.09	14.22	27.46	3.19 ab	0.21	0.86	0.25
100% ETc	0.14	0.09	0.11	14.25	14.79	4.19 b	0.25	0.67	0.38

Note : Numbers within the same column followed with different letters are significantly different with Duncan's Multiple Range Test (DMRT) 5%.

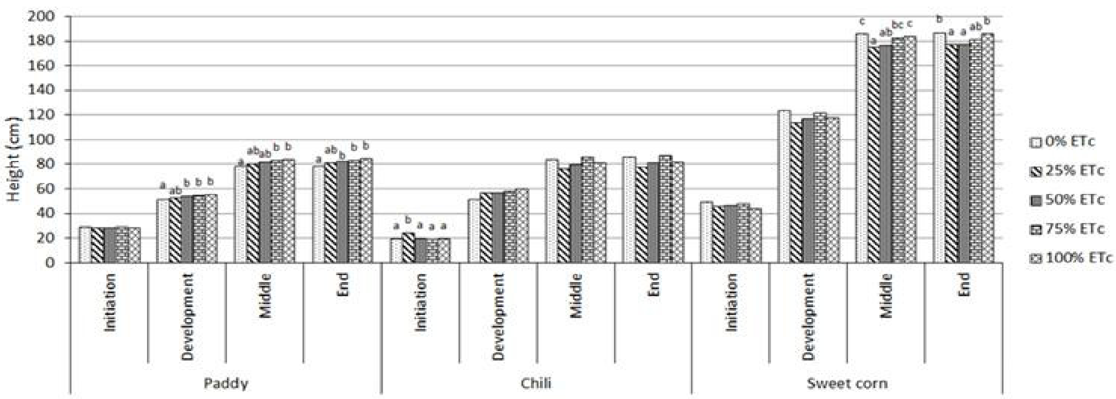


Figure 3. Plants Height (α=0,05)

4. Plant Height

Plant growth as parameters characteristic of plants is plant height presented in figure 3. The results of plant height observation are presented in figure 3. It is shown that in paddy, supplemental irrigation treatments significantly increased plant height compared to control, except at initial stage. On the other hand, plants' heights are not significantly different almost at all stages in chili and sweet corns. Those mean that irrigation treatments did not affect the growth of chili and sweet corn, probably because chili and sweet corn are crops with quite lower water requirement than paddy. Rainfall during experiment period was predicted to be adequate for chili and sweet corn, and thus the growth was not significantly different.

5. Crop Water Productivity (CWP)

Crop water productivity (CWP) of product and biomass of each crops are presented in figure 4. Product CWP means the CWP of yield, while biomass CWP is the CWP of total dry biomass. It is shown clearly that CWP of paddy are significantly affected by irrigation treatment, but insignificantly influenced chili and sweet corn. CWP of irrigation treatments in paddy are lower than control, due to rainfall was rather high (341.77 mm) and sufficient for paddy growth. The total rainfall from initial to mid stage (approx. 60 days) was 282.45 mm, and it was enough to fulfill crop water requirement. At the final stage (maturation process), the paddy does not require much water, and thus

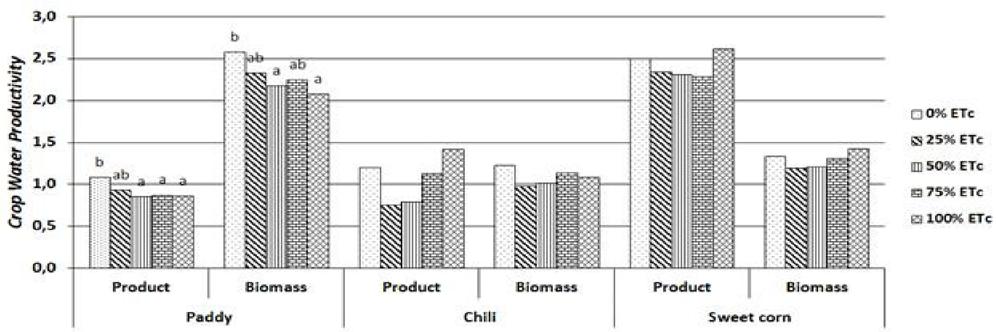


Figure 4. Crop water productivity (α=0,05)

without irrigation the rainfall was already enough. This condition led to low CWP in paddy.

Both product and biomass CWPs of chili and sweet corn are not significantly different than control, because the crop water requirements are lower than paddy, which was already sufficient from the rainfall. This means that the application of supplemental irrigation to chili and sweet corn is ineffective, if rainfall is still adequate because it cannot increase crop water productivity. Total water requirements of chili and sweet corn are 345.59 mm and 282.13 mm, respectively. However, recently it is hard to predict the weather, especially rain. Precipitation at the rain-fed area is fluctuating year by year and become more unpredictable,, and thus leads to the increasing of crop failure risk. Therefore, harvesting rainfall and runoff on rain-fed farming lands is very important to minimize the risk, because farmers can use the water at anytime when a break season (short drought) occurs. Food security can be achieved by increasing the potential of agricultural production with water management at the rain-fed area (Oweis and Hachum, 2012).

CONCLUSION

This research concluded that water from SFR with the size of 10m height × 3m width × 2m depth is sufficient to irrigate approx. 422.5 m^2 area cultivated with paddy, chili and sweet corn. The supplemental irrigation did not affect the CWP, when rainfall is adequate. However, SFR was inefficient due to high water loss (1.9 times higher than the total crop water requirements) through evapotranspiration and seepage.

REFERENCES

BPPP (2011). *Adaptation on climate change in agricultural sector (in Indonesian)*. Agricultural Research and Development Agency. Ministry of Agriculture. Indonesia.

BPTP (1997). *On farm reservoir as water collectors (in Indonesian).* Wonocolo Installation Research and Agricultural Technology Assessment. Karangploso Agricultural Technology Assessment Agency.

Case M, Ardiansyah F, Spector E (2007). *Climate change in Indonesia: Implications for humans and nature.* Brandeis University.

Djaenudin D, Marwan H, Subagjo H, Hidayat A (2011). Technical of Land Evaluation For Agricultural Commodities. Land Resources Research and Development Agency. Bogor. Indonesia.

FAO (1998). Single crop coefficient (Kc) : *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56.* Rome: FAO.

FAO(2008).CropWat. http://www.fao.org/nr/water/infores_databases_cropwat.html.

Guerra L, Watson P, Bhuaiyan S (1990). Hydrological characteristics of on-farm reservoirs in rainfed paddygrowing areas. J. *Agricultural Water Management, 17*: 351-366.

Hardjowigeno S (2007). *Soil Science (in Indonesian).* Jakarta: Akademika Pressindo.

Komariah, Setiawan A, Dewi WS, Sumani (2010). Analysis of Plants Water balance to determine of Cropping Land in Rainfed area in Gondangrejo district, *Karanganyar regency, Jawa Tengah province) (in Indonesian).* Manuscripts in review.

Komariah, Sumani, Dewi WS (2011). *Shifting season analysis as climate anomaly impact and impact on agricultural system change in dry land (Case study in Karanganyar regency, Jawa Tengah province) (in Indonesian). Report of Directorate General of Higher Education (DGHE). Ministry of Education and Culture. Indonesia.*

Molden D (1997). Accounting for Water Use and Productivity. *SWIM,*16.

Oweis T, Hachum A (2012). *Supplemental Irrigation: A Highly Efficient Water - Use Practice.* International Center for Agricultural Research in the Dry Areas (ICARDA).

Panigrahi B, Panda S, Agrawal A (2005). Water balance simulation and economic analysis for optimal size of on-farm reservoir. *Water Resources Management, 19*: 233-250.

Paul D, Tiwari K (1994). Rainwater storage systems for rainfed paddylands of eastern india: results from research in hazaribagh district. Dalam S. Bhuiyan (Eds), *On-farm reservoir systems for rainfed paddyland* (pp. 127-139). Philippines: IRRI.

Permentan (2007). *The key recommendations fertilizer of N, P, and K on the specific location of the wetland (per district) Jawa Tengah province.* http://www.litbang.deptan.go.id.

Pramudia A (2006). Rainy season in sentra production of rice has changed. *Sinar Tani* magazine.

PTP (2007). Integrated plant management of corn on dry land *Pengelolaan tanaman terpadu jagung di lahan kering beriklim kering*. www.puslittan.bogor.net.

Sager J, Farlane J (1997). Radiation. Langhans R, Tibbitts T (Eds). *Plant Growth Chamber Handbook* (Vol. 340). North Central Regional Research Publication.

Setiawati W, Murtiningsih R, Sopha G, Handayani T (2007). Technical instructions, Vegetables cultivation. Vegetables Research Agency. Horticulture Research and Development Agency. Agriculture Research and Development Agency, Indonesia.

Spomer L, Tibbitts T (1997). Humidity. Langhans R, Tibbitts T (Eds). *Plant Growth Chamber Handbook* (pp. 43-64). North Central Regional Research Publication.

Syamsiah I, Suprapto, Fagi A, Bhuiyan S (1994). Collecting and conserving rainwater to alleviate drought in rainfed paddylands of Indonesia. Bhuiyan S (Eds). *On-farm reservoir systems for rainfed paddyland.* Philippines.