Water use efficiency of *Coix lacryma-jobi* L. varieties in response to water supply according to CROPWAT analysis

Fiky Yulianto Wicaksono, Kadapi Muhamad*, Tati Nurmala

(Department of Crop Science, Faculty of Agriculture, Universitas Padjadjaran, Sumedang 45363, West Java, Indonesia)

Abstract: It is essential to evaluate the efficiency of water supply on varieties of crop, such as *Coix lacryma-jobi* L. (hanjeli), particularly in water management. *Coix lacryma-jobi* L. (hanjeli) is one of the crops that were not listed for crop coefficient (K_c) values to estimate the crop water use by CROPWAT ver 8.0. However, this study using the K_c values of sugar cane as approach to reveal actual evapo-transpiration (*ET*). Hanjeli comprises two varieties, namely *stenocarpa* and *ma-yuen*, which were used in this study to observe the water requirement for irrigation when cultivating agricultural products in a loamy soil using CROPWAT. The ET_a (mm day^{-1}) generated by CROPWAT was used to calculate the sprinkler operation time (T, hour day^{-1}) and added 0.5 hour day^{-1} to anticipate the less water when using K_c for sugarcane (T+0.5, hour day^{-1}) . The results showed that the trend of T+0.5 rapidly increased from the initial to mid-stage before slowing down from the mid to the late-stage. These indicated that the fluctuated water requirement in both varieties was in accordance with the growth stages. Furthermore, the water use efficiency revealed that the yield and economic usage of hanjeli increased when irrigation was applied in accordance with T+0.5 for sprinkler operation time, which is 1.27 and 0.11 times in dry and rainy seasons for *ma-yuen*. This study suggested that the CROPWAT estimation efficiently supplies water supply for the evapotranspiration of hanjeli varieties.

Keywords: adlay, climate, depletion, soil properties, tropic

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1 Introduction

According to Oldeman (1977), the dryland agriculture area in Sumedang district is classified into two climate zones, namely C3 and D2. Furthermore, it has the potential of becoming the canter of activities in Indonesia due to its large availability (Siregar and Suryadi, 2006). However, this area still needs to be irrigated due to weather factors such as rainfall intensity, soil characters, and ENSO effect (Gelcer et al., 2018). Drylands need a sufficient supply of water during the dry season for agricultural practice steadiness and in order to increase the cropping index (Siregar and Suryadi, 2006; Fu et al., 2019). According to Utami et al. (2019), dryland usually relies on rainfall water. Therefore, farmers usually wait for this season before carrying out the cultivation process to ensure the soil has enough nutrients (Utami et al., 2019).

El Niño Southern Oscillation, also known as ENSO, is an irregular variation in temperatures and wind flow that occurs in tropical regions (Susilo et al., 2013). According to Nur'utami and Hidayat (2016) and Supari et al. (2018), ENSO affects the time and amount of rainfall in Indonesia. Therefore, based on this condition, the water management needs to be accurate and according to the crop requirement, which is calculated using the evapotranspiration (*ET*) method (Jensen and Wright, 1978). Smith (1992) stated that the Food and Agriculture Organization (FAO) has released software capable of

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***Corresponding author: Kadapi Muhamad, Asst. Prof.,** Department of Crop Science, Faculty of Agriculture, Universitas Padjadjaran, Sumedang 45363, West Java, Indonesia. Tel: +62 22-84288890. Email: kadapi@unpad.ac.id.

calculating *ET* and estimate water necessity based on climate, crop types, and soil characteristics, namely as CROPWAT 8.0.

The Department of Crop Science, Universitas Padjadjaran (UNPAD), through the Hanjeli Team carried out an evaluation study to analyse the possibility of cultivating hanjeli (*Coix lacryma-jobi* L.) in West Java. The results showed that this crop is suitable for optional development in Sumedang district (Ruminta et al., 2017), which is classified into two climate zone (C3 and D2) and the fourth largest dryland agriculture area (61,500 ha) in West Java, Indonesia (Sukarman and Ritung, 2012; Rachmat, 2012). Hanjeli, also known as "adlay" and "job's tears," is one of the cereal crops that provide tremendous health benefits for human health and consumed as an additional staple food (Chung et al., 2011).

The two types of this crop are called as *stenocarpa* (hard shelled) and *ma-yuen* (soft shelled) (Kang et al., 2020). These crops have different agro-morpho-physiology that requires varying cultivation practice, particularly in irrigation. Generally, the one cycle growth of *ma-yuen* is shorter than *stenocarpa*, beside *ma-yuen* have soft shell (Rao and Nirmala, 2010). According to preliminary studies, a fundamental process is needed to efficiently supply water to the C3 and D2 agro-climate zones. The rise in human population decreases the availability of groundwater in agriculture area, due to excessive consumption, thereby leading to a rise in the number of critical zones for agricultural products (Hutasoit, 2009). Besides, the efficiency of rain in such areas also decreases due to high infiltration and runoff rate, which indicates sufficient irrigation (Bafdal et al., 2014).

2 Materials and methods

The Ciparanje, Sumedang district located 6.9164° S, and 107.7717° E, is a tropic climate. A 10-year meteorological data shows that this district has an average temperature, evaporation, dry season, and rainfall of 22.3°C, 157.7 mm, ± 6 months, and 3.3 mm, respectively. Figure 1 shows the Ciparanje experimental agriculture field of UNPAD, which represents the agricultural condition in Sumedang district. Due to the nature of the area, cultivation is usually postponed to the rainy season, with cropping carried out during this period, assuming there are no rivers close to the field. The main crop cultivated in this dryland is sweet potatoes because it requires less water compared to corn and soybean, with water requirements at 350.6 to 418.9 mm/season and 349.6 mm/season, respectively (Suryadi et al., 2018).

The ten-year meteorological data (2008-2018) was obtained from the Meteorological, Climatological, and Geophysical Agency (Indonesia) and weather station at Universitas Padjadjaran. All meteorological data consists of the following input requirements of the CROPWAT 8.0 software, namely temperature (°C), air humidity (%), and wind (m s^{-1}). The irradiation duration data were obtained from SOLPOS Calculator by inputting the date and site location, which is further converted according to the CROPWAT requirement (Mikofski, 2020).

The crop's characteristics data were derived from previous research carried out by Hanjeli Team from 2016-2018 in Sumedang, West Java. These traits consist of crop stages, plant height, and root depth of each hanjeli. In terms of crop coefficient (K_c), the critical depletion and yield response attributes were determined using the sugarcane pattern (FAO-56 guidelines). These criteria from previous studies were used due to inadequate research on the hanjeli crop to elucidate these data determine the similarity between these two crops, with the C4 in the Gramineae family. The soil characteristics used in this research, such as field capacity (FC) and permanent wilting (WP) were analyzed at the Physic Soil Laboratory of Universitas Padjadjaran, as shown in Figure 1. Furthermore, all data requirements utilized the FAO methods for field measurements (Zotarelli et al., 2010).

2.1 Research methods

The P-M formula designed by Monteith (1965) was used to calculate the ET_0 using CROPWAT after inputting the local meteorological data as follows:

$$ET_0 = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}u2(es-ea)}{\Delta+\gamma(1+0.34\,u2)} \quad (1)$$

In which, ET_0 is evapo-transpiration (mm day^{-1}), R_n is the net irradiation (W m^{-2}), G is the flux of soil heat (W m^{-2}), *(es- ea)* is the vapor pressure slope of the air between the capacity or saturation of vapor pressure and the actual vapor pressure (kPa), Δ is the gradient between vapor of saturation pressure and temperature, γ is constant of psychometric, T is for the daily temperature (°C) and $u2$ is the speed of wind flow (m s^{-1}) (Allen, 1998).

The next step was used ET_0 in accordance with the P-M formula to calculate water requirement of crop (CWR) represented as ET_c using the following formula:

$$ETc = Kc \times ET_0 \quad (2)$$

Where, K_c is the coefficient of crop. It is obtained by dividing ET_c (mm day^{-1}) by ET_0 (mm day^{-1}). K_c's value is different among crops and based on stages, which is divided into the initial, developmental, mid, and late seasons using CROPWAT ver. 8.0 (Allen, 1998). Furthermore, this research examined the K_c values in sugarcane crop with the data of morphological traits of hanjeli obtained by actual performance, such as rooting depth and crop height in 2019.

The last step in attaining irrigation requirement is associated with the initial available soil moisture (mm m^{-1}), which considers the field capacity and wilting point (Savva and Frenken, 2002). Furthermore, the water supply calculated during the dry season is calculated to determine the possible occurrence of irrigation. The sprinkler irrigation chosen for this study and the formula to obtain the operational time use are as follows (Prabowo et al., 2004):

$$T = ETa/SR \quad (3)$$

In which, T is operational time (h), ET_a is actual crop water use (mm day^{-1}, provided by CROPWAT ver. 8.0) and SR is sprinkler rate (m h^{-1}). The value of SR was obtained by this calculation:

$$SR = (n \times q)/A \quad (4)$$

Where, n is indicated number sprinkler head, q is sprinkler debit (m^3 hour^{-1}), and A is large of area (m^2).

To evaluate the technology that needs to be accepted by economic value, the water use efficiency (WUE) is calculated in accordance with Duan (2005) research. The calculation method is as follows:

$$WUE = (Y \times P)/ETc \quad (5)$$

Where WUE (Rp m^{-3}) is calculated by multiplying Y (Yield, t ha^{-1}) with P (Price, Rp kg^{-1}) to determine the crop market price, which is further divided by ET_c (mm) to obtain the crop water consumption. Besides, we follow suggestion of Xiao et al. (2019) that use cost (C) during cultivation to reveal the real economic value of water use efficiency. The formula as described by Xiao et al. (2019) as follow:

$$WUE = ((Y \times P) - C)/ETc \quad (6)$$

Figure 1 The location site and soil properties of experimental field were used in this study. The green color indicated the Sumedang district, West Java, Indonesia (green colour) that the experimental field located. The soil properties were obtained in 2018 (Map provided by DIVA GIS 1:2000000)

3 Results and discussion

3.1 Results

3.1.1 Meteorological conditions

The actual weather data in 2018 obtained from the UNPAD station was shown in Table 1 with an average, minimum, and maximum monthly air temperatures and humidity of 20.3°C, 28.7°C, and 87%, respectively. The monthly amount of rainfall during the study period recorded for the first and second 3 months was 0.75 mm and 165.3 mm. The constant sun duration is 12 hours per day because it is in a tropic region, while the range of wind flow speed was 4 to 6 km day^{-1}. Furthermore, the average ET_0 values obtained during the study was 5.06 (mm day^{-1}) by a range of 4.24 to 5.59 (mm day^{-1}). While, the effective rain versus actual rain was 1012.2 vs 1766 mm provided by CROPWAT ver. 8.0 calculations.

3.1.2 Crop water requirements

The sprinkler irrigation system in this study used groundwater as the main source beside rainfall. However, crop cultivation was usually postponed during the dry season due to the inadequate supply of water. In 2018, the weather data (rain) obtained in 2015 was used to predict the ET_c, ET_a, and T+0.5 for field irrigation because the number of dry seasons was 6 months that year. According to the calculation using CROPWAT ver 8.0, each variety of hanjeli crop used sugar cane K_c and actual soil condition (depletion). Figures 2 showed that the total amount of ET_c *stenocarpa* and ma-*yuen* during crop cycles were 952 mm dec^{-1} and 767.6 mm dec^{-1}, respectively. This can be further divided into 4 stages of hanjeli growth lengths, such initial (23.8 mm dec^{-1}), developmental (101.5 mm dec^{-1}), mid (295.6 mm dec^{-1}), and late (531.1 mm dec^{-1}) for *stenocarpa* variety. The ET_c of *ma-yuen* showed lower life cycle total 767.6 mm dec^{-1}, which consists of 6.8 mm dec^{-1}, 123 mm dec^{-1}, 360.7 mm dec^{-1}, and 277.1 mm dec^{-1} at the initial, developmental, mid, and late stages, respectively. The trend of depletion (%) appeared stagnant and higher during the dry season to at the beginning of the rainy season as well as from the initial to the end mid-season of crop stages for both hanjeli varieties that were cultivated (Figure 4).

Table 1 Meteorological data consisting temperature, relative humidity, wind flow, Sunshine duration, irradiation and evapotranspiration

Month	Min Temperature (°C)	Max Temperature (°C)	Humidity (%)	Wind (km h^{-1})	Sun (hours)*	Irradiation (MJ m^{-2} h^{-1})**	ET_0**
January	21	28	90	4	12	28.3	5.49
February	20.5	28.5	91	3	12	28.7	5.59
March	21	27.8	93	3	12	28.3	5.48
April	21	28.4	93	3	12	26.8	5.14
May	21	28	87	4	12	24.7	4.54
June	20.9	28.5	89	3	12	23.6	4.31
July	20	28.8	78	5	12	24	4.24
August	18.9	29.7	81	5	12	25.8	4.71
September	18.9	29.7	79	6	12	27.6	5.11
October	19	30.8	79	6	12	28.4	5.42
November	20.6	28.3	90	4	12	28.3	5.48
December	20.6	28.3	90	4	12	28.1	5.42

Note: * the data is sunshine duration from sunrise to sunset (from SOLPOS), ** the data was obtained by CROPWAT ver. 8.0 calculation

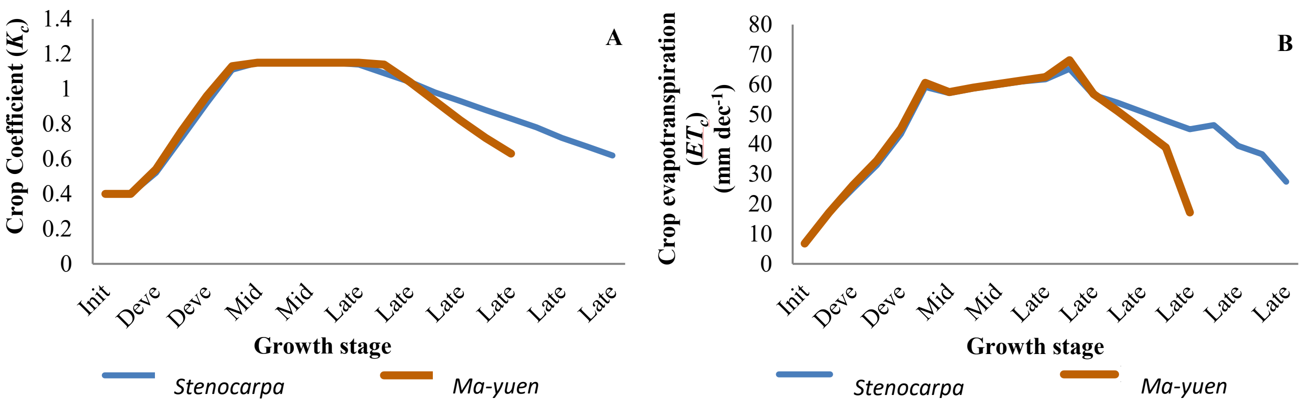

Figure 2 The crop coefficient (Kc) (A) and crop evapotranspiration (ET_c) (B) of two hanjeli varieties, *stenocarpa* and *ma-yuen*

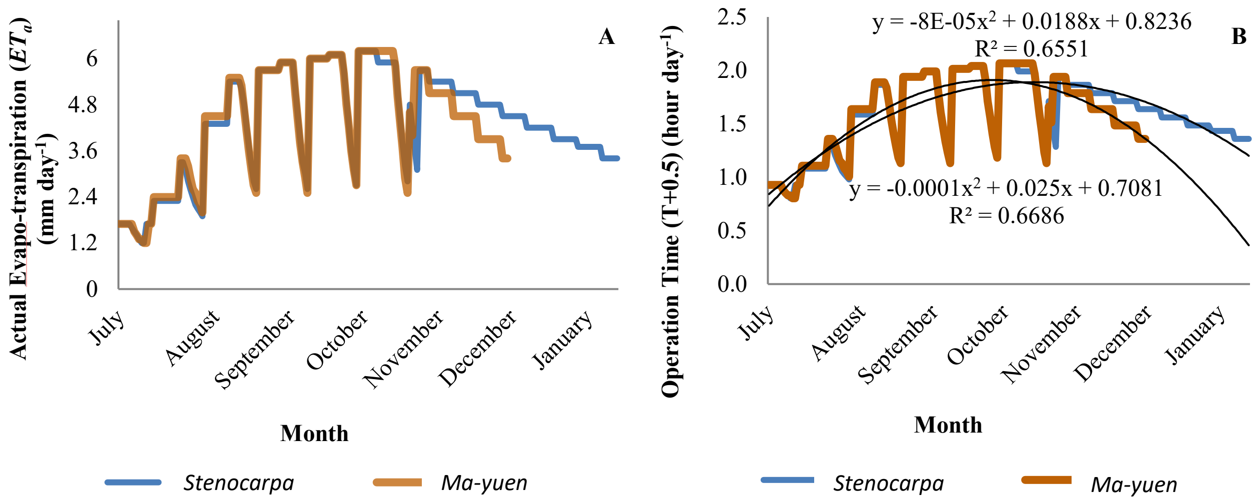

Figure 3 The actual evapo-transpiration (ET_a) (A) and operation time of sprinkler + 0.5 h (T+0.5) (B) use for irrigation of two hanjeli varieties, *stenocarpa* and *ma-yuen* in this study

The actual calculation in 2018 based on the use of rain data to predict the ET_c was similar to the 2015 data for *stenocarpa* and slightly different for ET_c at the developmental stage (123 mm dec^{-1} vs. 123.1 mm dec^{-1}) in *ma-yuen* variety (data un showed).

The ET_a is used as the input data to predict the time operation (T) of the sprinkler with the emitter debit of sprinkler head (q, 0.19 m^3 h^{-1}), which demonstrated the fluctuated time with an increase in trend according to the growth stage in both varieties of hanjeli, as shown in Figure 3. The longest time was 1.57 hour day^{-1} from the end of mid-stage to the beginning of the end-stage. However, half-hour (T+0.5) was added to the field time to anticipate the less water when using K_c for sugarcane. Hence the longest irrigation time was determined using sprinkler was ± 2 hours day^{-1}.

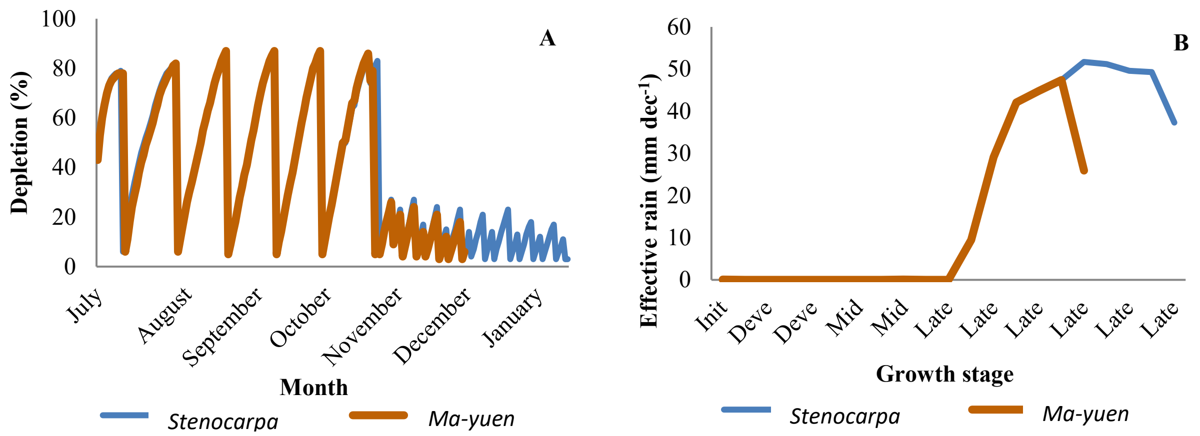

Figure 4 The depletion (A) and effective rain (B) to determine the ET_a and T for two hanjeli varieties, *stenocarpa* and *ma-yuen*

The operation time of sprinklers during the rainy season, which started from November to the end of the growth stage, was adjusted. The sprinklers carried out their activities any day accordance to the rain. In the previous study, the yield in the dry season versus in the rainy season of hanjeli was unstable. In which, the yield in dry season was 3 t ha^{-1} vs 6.1-6.3 t ha^{-1} in the rainy season for *ma-yuen* variety and 4.5 t ha^{-1} in the dry season for *stenocarpa* variety. The increasing yield of *ma-yuen* and *stenocarpa* varieties was showed by the actual data on the spot, 6.8 t ha^{-1} for *ma-yuen* variety and 6.4 t ha^{-1} for *stenocarpa* variety when irrigated using the ET_a for base data to calculate duration and volume of irrigation according to CROPWAT (Table 2).

3.1.3 Crop water use efficiency

Based on the calculation, the *WUE* was different between seasons and between varieties. The range of WUE_1 was 1954.14 to 4429.39 Rp m^{-3} and WUE_2 was 1498.51 to 3398.33 Rp m^{-3}. The lowest WUE_1 was for *ma-yuen* variety in dry season (2017), while, the highest

WUE_1 and WUE_2 was *ma-yuen* variety in dry season using irrigation calculation based on CROPWAT ver 8.0 results (Table 2).

Table 2 The crop yield and water use efficiency of two hanjeli varieties in two seasons

Variety	Season	Year	Crop Yield (t ha^{-1})	Price (Rp kg^{-1})	Cost (Rp)	*ETC* (mm)	WUE_1 (Rp m^{-3})	WUE_2 (Rp m^{-3})	References
Ma-yuen	Rainy	2016	6.100	5000	9000000	790.3	3859.29	3048.86	Ruminta et al., 2019
	Rainy	2016	6.300	5000	10000000	790.3	3985.83	3148.73	Nurmala et al., 2016
	Dry	2017	3.000	5000	11400000	767.6	1954.14	1498.51	Ruminta et al., 2018
	Dry*	2018	6.800	5000	12800000	767.6	4429.39	3398.33	Actual
Stenocarpa	Rainy	2016	4.500	5000	10000000	962	2234.93	2148.96	Nurmala et al., 2017
	Dry*	2018	6.400	5000	12800000	952	3361.34	3198.66	Actual

Note: [1] is provided by formula 5 and [2] is resulted by formula 6. Rp is Rupiah (Indonesian Rupiah Rate currency, IDR)

3.2 Discussion

The variation in ET_0 values was detected using the CROPWAT software, which indicated fluctuations in air temperatures, relative humidity, and wind flow speed during the years in this area. Particularly, the maximum temperature and wind flow speed in dry seasons. A similar phenomenon is reported in other tropic region during dry season (de Azevedo et al., 2007). In this study, the values of ET_c become high through the growth phase and reach the maximum at mid phase. Finally, ET_c showed a slight decrease in the two types of hanjeli with a total maturity time of 162 and 206 days for *ma-yuen* and *stenocarpa*, respectively. The late stage of *ma-yuen* was 55 days earlier than *stenocarpa*, thereby indicating differences in both varieties. These results suggested that this period was critical for water supply, which is more efficient during dry season (Cakir, 2004).

The CROPWAT setting in rain input to estimate the effective rain while the USDA S.C. method was used to determine the irrigation requirement. Besides, the K_c as coefficient of crop was presented by CROPWAT divided into decade based on growth and developmental crop stages. The vary K_c of *ma-yuen* vs *stenocarpa* variety as shown in Figure 2 indicated that the late stage play important role that determine ET_c as explained earlier. Although the K_c values vary, the trend increased rapidly from initial to end development and become stagnant at mid stage. Lastly, the K_c values slowly decreased in late stage, thereby indicating that the CROPWAT closed to present sigmoid growth curve of each hanjeli variety by considering evapo-transpiration. Furthermore, the depth of crop rooting and water holding that may determine the amount of water to irrigate these two varieties (Borg and Grimes, 1986; Cakir, 2004; Song et al., 2010; Akinbile et al., 2020). The effective rain in the first to the late mid-stage (July to November) was 0, this indicating that no rain and hanjeli crop varieties relied on irrigation water. Therefore, it is clear that the yield of these two varieties in this study was determined by water supply.

The crop yield in the dry season has the ability to exceed those harvested in the rainy season with the supply of adequate water according to ET_a as actual crop evapotranspiration. These results suggested that the irrigation system such sprinkler by weight on growth and developmental stage of crops, water availability and soil characteristics was important in the term to save water. Liu et al. (2013) suggested that sprinkler is more effective compare to surface irrigation in wheat cultivation. Besides, the irrigation application by refill soil to field capacity and supplied at *ET* crop reduction per stage provided the total amount of water available to the crop (Jensen et al., 1990; Ewaid et al., 2019). The flooding/surfacing irrigation from pond that usually chosen by farmers was ineffective even less in price due to difficult to control the amount water of irrigation. This process was revealed for the two varieties of hanjeli as reflected by the efficient use of water considering the price of yield, input during cultivation, and evapotranspiration. Furthermore, the water use efficiency showed that the yield increases of two hanjeli varieties due to proper irrigation. Particularly, it could be seen in comparison between dry seasons for *ma-yuen*. Besides, the yield of *stenocarpa* variety irrigated by sprinkler was higher during the dry season than the yield of this crop in the rainy season, thereby indicating that the irrigation system was suitable. As reported by Alberto et al. (2013) that the sprinkler irrigation system could increase the water efficiency up to 50% and provides numerous benefits for farmers. According to the shorter growing period, the *ma-yuen* was more efficient in water use and more profitable for farmers. Moreover, the cropping rotation/sequence by another crop to increase the number of cropping index is feasible due to the end stage of *ma-yuen* was still in rainy season. Due to the data of this study was just from short-term experiments of two hanjeli varieties. The long-term field observations data are needed to examine water use efficiency in cropping rotation/sequence pattern by measuring the important agronomic traits of each crop. As suggested by Zhang et al (2015) that the water use efficiency of crops could change and need to be properly evaluated due to the agronomic practice, crop variety/species and environment in order to avoid the yield decline. Besides, the irrigation techniques for each crop in cropping system need to be observed (Evans and Sadler, 2008).

4 Conclusions

The crop water requirements analysis using CROPWAT to estimate water requirements of two hanjeli varieties was effective in increasing water use efficiency for both varieties in this study. The CROPWAT can provide sufficiently the crop evapotranspiration simulation that is useful to calculate the irrigation duration for two hanjeli varieties. Furthermore, the scheduling of irrigation timing according to *ET* crop reduction per stage and refill soil to field capacity providing the advantage in yield for both varieties due to the irrigation volume and time were based on interaction between crop and environment. The growth stages showed as the key input to simulate the water loss by evapo-transpiration and the soil properties support to determinate the precision irrigation quota of both varieties. The sugar cane *Kc* use in this study was useful to estimate the ET_c for hanjeli varieties.

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References

Akinbile, C. O., A. Ogundipe, and R. O. Davids. 2020. Crop water requirements, biomass and grain yields estimation for upland rice using CROPWAT, AQUACROP and CERES simulation models. *CIGR Journal*, 22(2): 1-20.

Alberto, M. C. R., R. J. Buresh, T. Hirano, A. Miyata, R. Wassmann, J. R. Quilty, T. Q. Correa Jr, and J. Sandro. 2013. Carbon uptake and water productivity for dry-seeded rice and hybrid maize grown with overhead sprinkler irrigation. *Field Crops Research*, 146: 51-65.1

Allen, R. G., L. S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Rome： FAO.

Bafdal, N., S. D. NP, and K. Amaru. 2014. Analisis rasio luas daerah tangkapan air (*catchment area*) dan areal budidaya pertanian (*cultivated area*) dalam desain model run off management integrated farming di lahan kering. *Journal of Civil Engineering*, 21(3): 205-212.

Borg, H., and D. W. Grimes. 1986. Depth development of root with time:an empirical description. *Transactions of ASAE*, 29(1): 194-197.

Cakir, R. 2004. Effect of water stress at different developmental stages on vegetative and reproductive growth of corn. *Field Crops Research*, 89(1): 1-16.

Chung, C. P., S. M. Hsia, M. Y. Lee, H. J. Chen, F. Cheng, L. C. Chan, Y. H. Kuo, Y. Lin, and W. Chiang. 2011. Gastroprotective activities of adlay (*Coix lacryma-jobi* L. var. *ma-yuen* Stapf) on the growth of the stomach cancer AGS cell line and indomethacin-induced gastric ulcers. *Journal of Agricultural and Food Chemistry*, 59(11): 6025-6033.

de Azevedo, P. V., C. B. de Souza, B. B. da Silva, and V. P. R. da Silva. 2007. Water requirements of pineapple crop grown in a tropical environment, Brazil. *Agricultural Water Management*, 88(1-3): 201-208.

Duan, A. W. 2005. Connotation of water use efficiency and problems needing attention in use. *Journal of Irrigation and Drainage*, 24: 8-11.

Evans, R. G., and E. J. Sadler. 2008. Methods and technologies to improve efficiency of water use. *Water Resources Research*, 44(7): W00E04.

Ewaid, S. H., S. A. Abed, and N. Al-Ansari. 2019. Crop Water requirements and irrigation schedules for some major crops in southern Iraq. *Water*, 11(4): 756.

Fu, Q., L. Yang, H. Li, T. Li, D. Liu, Y. Ji, M. Li, and Y. Zhang. 2019. Study on the optimization of dry land irrigation schedule in the downstream Songhua River Basin Based on the SWAT Model. *Water*, 11(6): 1147.

Gelcer, E., C. W. Fraisse, L. Zotarelli, D., Perondi, H. A. Malia, C. C. Ecole, and K. W. Migliaccio. 2018. A smart irrigation tool to determine the effects of enso on water requirements for tomato production in Mozambique. *Water*, 10(12): 1820.

Hutasoit, L. M. 2009. Kondisi permukaan air tanah dengan dan tanpa peresapan buatan di daerah Bandung: hasil simulasi numerik. *Jurnal Geologi Indonesia*, 4(3): 177-188.

Jensen, M. E., and J. L. Wright. 1978. The role of evapotranspiration models in irrigation scheduling. *Transactions of the ASAE*, 21(1): 82-87.

Jensen, M. E., R. D. Burman, and R. G. Allen. 1990. Evapotranspiration and irrigation water requirements. New York, NY: ASCE.

Kang, S. H., B. Kim, B. S. Choi, H. O. Lee, N. H. Kim, S. J. Lee, H. S., Kim, M. J. Shin, H. W. Kim, K. Nam, K. D. Kang, S. J. Kwon, T. J. Oh, S. C. Lee, and C. K. Kim. 2020. Genome assembly and annotation of soft-shelled adlay (*Coix lacryma-jobi* Variety ma-yuen), a cereal and medicinal crop in the poaceae family. *Frontiers in Plant Science*, 11: 630.

Liu, H., Y. Kang, S. Yao, Z. Sun, S. Liu, and Q. Wang. 2013. Field evaluation on water productivity of winter wheat under sprinkler or surface irrigation in the North China plain. *Irrigation and Drainage*, 62(1): 37-49.

Mikofski, M. 2020. Solar Position Calculator. Available at: https://www.mathworks.com/matlabcentral/fileexchange/58405-solar-position-calculator. Accessed 7 August 2020.

Monteith, J. L. 1965. Evaporation and environment in the state and movement of water in living organism. In *Proc. of the Society for Experimental Biology, Symposium No. 19*, 205-234. Cambridge, 1 January

Nurmala, T., Ruminta, and A. Wahyudin. 2017. Respons pertumbuhan dan hasil tanaman hanjeli batu (*Coix lacryma-jobi* L.) akibat pupuk silika cair dan paclobutrazol. *Jurnal Kultivasi*, 16(3): 474-481.

Nurmala, T., A. Yuniarti, and N. Syahfitri. 2016. Pengaruh berbagai dosis pupuk silika organik dan tingkat kekerasan biji terhadap pertumbuhan dan hasil tanaman hanjeli pulut (*Coix lacryma-jobi* L) genotip 37. *Jurnal Kultivasi*, 15(2): 133-142.

Nur'utami, M. N., and R. Hidayat. 2016. Influences of IOD and ENSO to Indonesian rainfall variability: role of atmosphere-ocean interaction in the Indo-Pacific sector. *Procedia Environmental Sciences*, 33: 196-203.

Oldeman, L. R. 1977. Climate of Indonesia. In *Proc. of Sixth Asian-Pacific Weed Science Society Conf.*, 14-30. Jakarta, 11-17 July.

Prabowo, A., A. Prabowo, and A. Hendriadi. 2004. Pengelolaan Irigasi Hemat Air di Lahan Kering: Aplikasi Irigasi Tetes dan Curah. Available at: https://mekanisasi.litbang.pertanian.go.id/ind/index.php/galeri-media/download1/category/21-makalah-seminar. Accessed 17 August 2021.

Rachmat, M. 2012. Pembangunan jangka menengah Jawa Barat dan prospek pengembangan pertanian lahan kering. In *Prospek Pertanian Lahan Kering Dalam Mendukung Ketahanan Pangan*, eds. Dariah, A., B. Kartiwa, N. Sutrisno, K. Suradisastra, M. Sarwani, H. Soeparno, E. Pasandaran, ch. V, 350-366. Jakarta: IAARD Press.

Rao, P. N., and A. Nirmala. 2010. Chromosomal basis of evolution in the genus *Coix* L. (Maydeae): a critical appraisal. *The Nucleus*, 53(1-2): 13-24.

Ruminta, T. Nurmala, and F. Y. Wicaksono. 2017. Growth and yield of Job's Tears (*Coix lacryma-jobi* L.) response to different types of oldeman climate classification and row spacing in West Java Indonesia. *Journal of Agronomy*, 16(2): 76-82.

Ruminta, T. Nurmala, A. W. Irwan, and Y. A. Surbakti. 2019. Respons pertumbuhan dan hasil tanaman hanjeli (*Coix lacryma-jobi* L.) terhadap kombinasi jarak tanam dan jenis pupuk kandang di dataran medium Sukasari, Sumedang. *Juanal Kultivasi*, 18(2): 903-911.

Ruminta, T. Nurmala, Y. Yuwariah and N. Y. Pratiwi. 2018. Respon pertumbuhan dan hasil tanaman hanjeli pada panen awal akibat pemberian dosis pupuk biosilika dan paklobutrazol di lahan kering Jatinangor. *Jurnal Kultivasi*, 17(3): 694-700.

Savva, A. P., and K. Frenken. 2002. Crop Water Requirements and Irrigation Scheduling. Irrigation Manual Module 4. Harare, Zimbabwe: Water Resources Development and Management Officers, FAO Sub-Regional Office for East and Southern Africa.

Siregar, M., and M. Suryadi. 2006. Enhancing sustainable development of diverse agriculture in Indonesia. CAPSA Working Paper No. 97. Bangkok, Thailand: Economic and Social Commission for Asia and the Pacific.

Smith, M. 1992. CROPWAT: a Computer Program for Irrigation Planning and Management. FAO Irrigation and Drainage Paper No. 46. Rome, Italy: FAO.

Song, Y., C. Birch, S. Qu, A. Doherty and J. Hanan. 2010. Analysis and modelling of the effects of water stress on maize growth and yield in dryland conditions. *Plant Production Science*, 13(2): 199-208.

Sukarman, I. G. M., and S. Ritung. 2012. Identifikasi Lahan Kering Potensial untuk Pengembangan Tanaman Pangan. In *Prospek Pertanian Lahan Kering Dalam Mendukung Ketahanan Pangan*, eds. Dariah, A., B. Kartiwa, N. Sutrisno, K. Suradisastra, M. Sarwani, H. Soeparno, and E. Pasandaran, ch. V, 316-328. Jakarta: IAARD Press.

Supari, T. F., E. Salimun, E. Aldrian, A. Sopaheluwakan, and L. Juneng. 2018. ENSO modulation of seasonal rainfall and extremes in Indonesia. *Climate Dynamics*, 51(7): 2559-2580.

Suryadi, E., D. R. Kendarto, B. A. Sistanto, D. Ruswandi, and S. Dwiratna. 2018. A study of crop water needs and land suitability in the monoculture system and plant intercropping. *International Journal on Advanced Science, Engineering and Information Technology*, 8(2): 554-560.

Susilo, G. E., K. Yamamoto, T. Imai, Y. Ishii, H. Fukami, and M. Sekine. 2013. The effect of ENSO on rainfall characteristics in the tropical peatland areas of Central Kalimantan, Indonesia. *Hydrological Sciences Journal*, 58(3): 539-548.

Utami, T. I., Handayani, T., and Kuswantoro. 2019. Exposure of dryland farming to the ENSO phenomenon in Kebumen District. *IOP Conference Series: Earth and Environmental Science*, 303(1): 012024.

Xiao, X., L. Fan, X., Li, M. Tan, T. Jiang, L. Zheng, and F. Jiang. 2019. Water-use efficiency of crops in the arid area of the middle reaches of the Heihe River: taking Zhangye City as an example. *Water*, 11(8): 1541.

Zhang, J., W. Ren, P. An, Z. Pan, L. Wang, Z. Dong,D. He, J. Yang, S. Pan, and H. Tian. 2015. Responses of crop water use efficiency to climate change and agronomic measures in the semiarid area of Northern China. *PLoS One*, 10(9): e0137409.

Zotarelli, L., M. D. Dukes, C. C. Romero, K. W. Migliaccio, and K. T. Morgan. 2010. Step by Step Calculation of the Penman-Monteith Evapotranspriation (FAO-56 Method). Florida, USA: Agricultural and Biological Engineering Dept., Florida Cooperative Extension Service, Institute of Food and Ag Sciences, Univ. of Florida.