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Determination of crop coefficient (Kc) of Sago Palm (*Metroxylon sagu*) on several growth stages

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ABSTRACT

Sago palm productivity and quality of wetland sago starch are still relatively low. Rainfed dryland is sufficient potential for sago palm development if plant water needs are met. Crop coefficients are important in predicting crop water requirements. The determination of crop coefficients was carried out on three stages of sago plant growth (initial-stage, mid-stage, and end-stage). The estimation of standard evapotranspiration is conducted using the Penman-Monteith method with the Cropwat 8.0 application. The estimation of sago palm evapotranspiration utilizes the lysimeter method on the initial-stage and plot observation in the mid-stage and end-stage. The determination of the crop evapotranspiration adheres to the water balance principle. Crop coefficient values are obtained by comparing standard evapotranspiration with the crop evapotranspiration. The results obtained are standard evapotranspiration at the study site 3.91 mm/day. Sago palm evapotranspiration is different in each growth phase (initial stage of about 2.44 mm/day, mid-stage of about 2.91 mm/day, and end-stage of about 3.82 mm/day. The crop coefficient of sago palm in the initial stage of growth that is 0.62, the mid-stage is 0.77 and the end-stage of growth is 0.98. The Kc value is used to predict the water needs of sago palm if they are to be developed in rainfed dryland areas.

***Key words :** Evapotranspiration, Water management, Water balance, Penman-Monteith, Sago palm.*

Introduction

The world is facing two major crises namely the food crisis (Xu, 2019) and the energy crisis (Sarkodie *et al.,* 2019). The food crisis is triggered by global warming (Dinu, 2019) and unequal distribution (Yesilada, 2019). Sago is one food source that can be a solution to the world food crisis (Ehara and Johnson, 2018). Sago has now shown considerable sustainability potential based on its use due to its variations (Syartiwidya *et al.,* 2019), as an alternative source of sugar (Bujang, 2018), as organic fertilizer (Talakua and Rich, 2019), and all parts of sago morphology have economic benefits and values.

The efforts to develop sago in various processing technologies, especially sago starch production, are not as fast as technology at the cultivation level in order to support the fulfillment of sago raw materials. National sago demand is currently reaching 1 million tons per year, while sago starch production is only around 400,000 tons per year (Indonesian Ministry of Agriculture's Food Security Agency, 2018). The data explains that additional 600,000 tons of sago starch are needed annually. In contrast, the fact is that the general community limits its own understanding that sago is a plant that grows on waterlogged lands, along river banks. Although there have been many research results that suggest that basically sago will grow well and produce maximum if planted on dry land or not flooded as long as water requirement is met.

Potential development of sago in rainfed dryland has been conveyed by Leuhenapessy (1996) and Botanri *et al.,* (2011). Their researches show a significant difference in the production of 343 kg per stem in sago growing in dryland, whereas in the inundated land the average production is only 125 kg per stem. The decline in production on stagnant land is rational because the land is dominated by sapling and weaning phases. This condition creates fierce competition in obtaining nutrition to support the growth process. One of the causes of low productivity in stagnant land is the difficulty of forming the main stem as a result of the dominance of tillers. Botanri *et al.* (2011) suggest that 85% of sago stem-forming failure is due to the dominance of tillers. This is also evident in the Rongkong watershed with an area of 1,453.08 ha of sago land, dominantly wetlands (downstream of the watershed), the average productivity of 1,917.45 kg/ha/year (Department of Horticultural Food Crops and Plantation of North Luwu, 2017) which is below the standard of 2 tons/ha (Ahmad, 2014). This fact reinforces the urgent need to extend the planting of sago 9from the lowlands to the highlands, from flooded to dryland, as long as water requirements in the metabolism process are met.

Increasing sago productivity in rainfed dryland is possible as long as sufficient water supply for plant growth and metabolism is present (Veres *et al.,* 2019), and, as stated by Tang *et al.* (2019), the management of rainwater as the sole source of water is done properly. One of the potentials of the Rongkong watershed is the high rainfall of above 200 mm per month (dryland, wet climate). Optimizing the utilization of water production from the rain in the upstream part of the Rongkong watershed to increase sago crop production should be considered. The basic policy of developing sago on rainfed dryland is refutable due to the absence of the data of the water supply required to cultivate the sago. Fulfillment of plant water needs can be conducted properly if the plant coefficient as an important parameter in estimating plant water needs is known. Data on plant coefficients for several types of plants are available in the FAO database, but for sago plants there are none. The determination of crop coefficients through direct measurements in the field is uncompromised regardless of the difficulty. The approach taken to determine the value of the crop coefficient of sago palm is to use the water balance principle through direct measurement of the water balance component at each phase of plant growth. Plants are grouped into three growth stages, namely the initial stage, the mid stage, and the end stage. The purpose of this research is to determine the crop coefficient value of sago palm in the initial stage of growth, the mid stage of growth, and the end stage of growth to predict the water needs of sago plants. The Kc value then becomes the basis for sago land water management strategies in rainfed dryland.

Materials and Methods

The study area

The research was carried out in the Rongkong watershed area of North Luwu Regency, South Sulawesi, Indonesia, precisely in the sago orchard of Pimbunian Village (sago demonstration plot covering 1 ha with hydrological conditions of dryland or groundwater level below the root zone). Water balance parameter measurements were carried out for 4 months (December 2018 to March 2019). The timing considered the representation of rainfall conditions at the study site (rainfall measurements have been calibrated with rainfall from the local meteorology climatology and geophysics agency).

Study method

Estimation of standard evapotranspiration (ETo) with the Penman-Monteith method

This variable applied a number of data including maximum and minimum temperature (C), humidity (%), wind speed (km/day), exposure time (hours), and solar radiation (MJ/ m/day). The data were obtained at the Meteorology Climatology and Geophysics Agency Andi Jemma, North Luwu Regency for the past 10 years (2008 - 2018). The method applied to calcuend the standard evapotranspiration value was the Penman-Monteith method (Equation 1). Δ

$$ETo = \frac{0.408\ \Delta\ (Rn - G) + \gamma\ (900/T+273)\ U_2\ (VPD)}{\Delta + \gamma\ (1 + 0.34U_2)}$$

Information:
ETo = potential Evapotranspiration (mm)
γ = psychometer coefficient

Rn = net radiation (mm/day)
G = change in saturated soil heat deposits
Δ = changes in saturated vapor pressure associated with changes in air temperature
T = air temperature (C)
U2 (VPD) = wind speed at an altitude of 2 m above ground level (km/hr)

ETo analysis was conducted employing the Cropwat version 8.0 application. This application also analyzed the effective rainfall (P-eff), to determine the land water balance chart in a surplus or deficit condition if there is a change in sago-based land use.

Estimation of plant evapotranspiration (ETa) with the water balance method

Evapotranspiration value of sago palm was observed in three growth stages, namely initial stage, mid stage, and end stage. The selected initial stage is one-year-old sago plant (sago palm seeds) (Fig. 1), the mid stage is sago palm which is around 4 years old or the stages where the main stem has not yet formed (Fig. 2), and the end stage is the tree phase with an age of 8 years the height of trees is around 7-8 meters (Fig. 3). The measurement of water balance components for the initial stage of growth employed 4 units of lysimeter drainage. The mid and end stages of growth use the observation plot in a 1 ha of dryland sago demonstration plot. The number of plots was 6 with an area of 2,828.57 cm^2 per plot. Around the observation area was also equipped with a simple ombrometer unit to measure actual rainfall. Observations were carried out from December 2018 to March 2019.

The ETa estimation uses asaz water balance (Asdak, 2007; Ayu *et al.*, 2013):

$$ETa = (P + I + U) - (R + D + \Delta S)$$

Fig. 1. Sago palm in the initial stage

Fig. 2. Sago palm in the mid stage

Fig. 3. Sago palm in the end stage

Information:
ETa = Evapotranspiration of plants (mm)
P = Presipitation (mm)
I = Irrigation /splash water (mm)
U = Capillary water up from ground water (mm)
R = Run off (mm)
D = Percolation (mm)
ΔS = Moisture content of the soil (mm)

The water balance components and their measurement methods are presented in Table 1.

Determination of crop coefficients (Kc)

Plant coefficient was the ratio of ETo to ETa. The crop coefficient (Kc) of sago palm as determined using the equation (Allen, 1998):

$$Kc = ETc / ETo$$

Information:
Kc = crop coefficient
ETa = Evapotranspiration of plants measured in the field (mm)
ETo = Standard evapotranspiration (mm)

Results

Standard evapotranspiration (ETo)

The results of the analysis of several climatological and meteorological parameters sourced from the Bureau of Meteorology, Climatology, and Geophysics Andi Jemma of North Luwu Regency using the Penman-Monteith method produce a standard evapotranspiration (ETo) value for the research site. The annual average ETo value can be seen in Fig 4. The complete analysis results are presented in Table 2.

Sago palm evapotranspiration (ETa) in initial stage, mid stage, and end stage

Direct measurement in the field to determine the

Table 1. Method of measuring water balance components used in determining crop evapotranspiration in the field.

No.	Water Balance Components	Method	Formula	Information	Reference
1.	Precipitation (P)	Drainage ombrometer	P = Pv / A	Pv = measured rain volume (ml) A = Surface area of rain gauge Rainfall <0.5 mm (ignored)	Tjokrodiningrat *et al.*, 2016
2.	Irrigation/ splash (I)	splash water	-	Iv = the volume of splash water (ml)	-
3.	Capillary water (U)	-	-	Ignored because the water table is under the root zone	-
4.	Runoff (R)	Drainage Lysimeter and planting plot	R = Rv/A	Rv = volume run off (ml) A (plot) = Area of plot (m); A (lysimeter) = Surface area of lysimeter	Hatiye *et al.*, 2019
5.	Percolation (D)	Darcy's Law; SPAW model	$q = -K(\theta) \times dH/dZ$ D = q x t	q = volume of land in excess of area per unit time (cm^3/sec) -K (θ) = unsaturated hydraulic conductivity dH = difference in hydraulic potential dZ = depth difference (cm) dH / dZ = hydraulic potential gradient D = water percolation (mm) t = time of percolation (hour)	Hillel, 1971; Saxton *et al.*, 2006
6.	Changes in Soil Moisture (˜S)	Gravimetric	Ow = Ww/ Ws Ov = B x Ow S= Ov x soil depth $\Delta S = S_n - S_{(n+1)}$	Ow = soil moisture based on weight (g / g) Ww = Weight of water in soil (g) Ws = Weight of dry soil (g) Ov = Moisture Volume (g/cm^3) B = density of soil (g/cm^3) ΔS = Changes in moisture content (mm) Sn = Moisture content of the previous period (mm) S (n + 1) = Moisture content of the period after that	

Table 2. Results of standard evapotranspiration analysis (ETo) employing the Penman-Monteith method.

Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate...

Country: Indonesia — Station: ANDI JEMMA- Luwu Uta

Altitude: 50 m. — Latitude: 2.35 °S — Longitude: 120.20 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	22.0	33.1	81	112	5.2	17.2	3.94
February	23.0	33.0	81	104	5.6	18.3	4.12
March	22.9	32.7	83	104	5.6	18.3	4.07
April	22.9	32.5	83	104	5.8	17.9	3.94
May	23.0	32.1	83	112	5.6	16.5	3.66
June	22.4	31.2	84	95	3.6	13.1	2.95
July	22.1	30.6	84	121	4.2	14.1	3.14
August	21.8	31.1	82	112	5.1	16.3	3.55
September	21.9	32.4	78	121	6.8	19.8	4.36
October	22.5	33.3	77	112	7.5	21.1	4.68
November	22.9	33.6	80	130	6.9	19.8	4.50
December	23.1	33.0	82	121	5.4	17.3	3.97
Average	**22.5**	**32.4**	**82**	**112**	**5.6**	**17.5**	**3.91**

Source: Results of secondary data analysis in the last 10 years (2008 - 2018) with Cropwat 8.0 application.

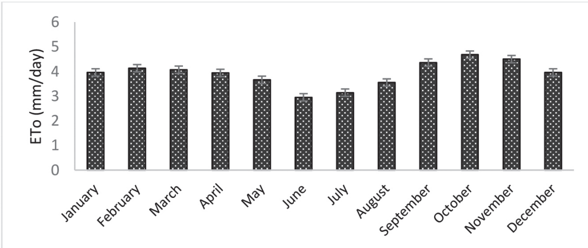

Fig. 4. Standard evapotranspiration (ETo) research sites.

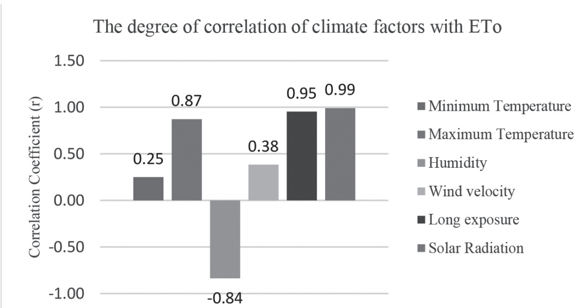

Fig. 5. Correlation coefficient (r) of climate factors on standard evapotranspiration

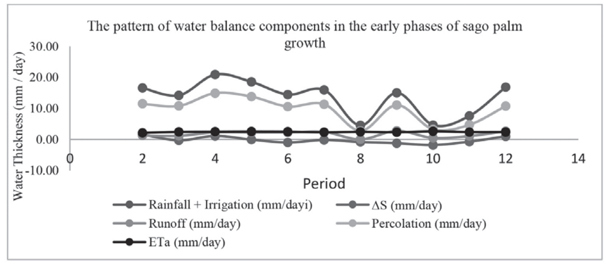

Fig. 6. Water balance components in the initial stage of the sago palm

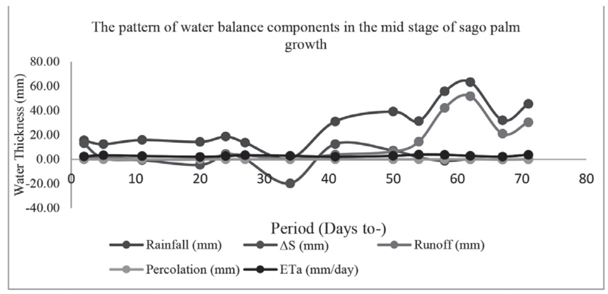

Fig 7. The sago land water balance pattern in the mid stage.

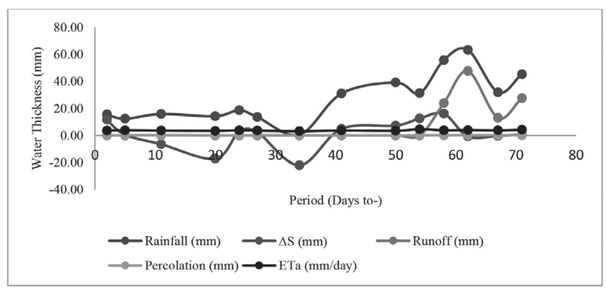

Fig. 8. The sago land water balance pattern in the end stage.

actual evapotranspiration value follows the water balance level. Measurements were made in three major groups based on the growth phase, namely the initial stage, mid stage, and end stage. The results of the analysis are shown in Tables 3, 4, and 5.

The pattern of water balance components in the early, mid and end stages of sago palm growth can be seen in Figures 6, 7 and 8. The evapotranspiration pattern of sago palm in the three growth phases can be seen in Figure 10.

Table 3. Crop Evapotranspiration (ETa) values for initial stage

Period	Rainfall + Irrigation (mm/day)	Δ S (mm/day)	Runoff (mm/day)	Percolation (mm/day)	Ro + P + ΔS (mm/day)	ETa (mm/day)
31-Dec-18	16.62	1.66	1.30	11.52	14.47	2.15
5-Jan-19	14.20	-0.25	1.18	10.82	11.74	2.46
10-Jan-19	20.94	1.16	2.33	14.93	18.42	2.52
15-Jan-19	18.58	-0.04	2.25	13.80	16.01	2.56
20-Jan-19	14.47	-0.94	2.27	10.61	11.94	2.52
25-Jan-19	15.96	-0.16	2.43	11.36	13.63	2.33
30-Jan-19	4.53	-0.80	0.05	2.79	2.05	2.49
4-Feb-19	15.04	-1.19	2.77	11.11	12.69	2.35
9-Feb-19	4.66	-1.78	0.51	3.28	2.01	2.65
14-Feb-19	7.59	-0.68	1.12	4.74	5.17	2.42
19-Feb-19	16.87	1.04	2.65	10.76	14.45	2.42
Average (mm/day)						2.44

Source: Results of primary data analysis.

Table 4. Crop evapotranspiration (ETa) values for mid stage

Days to-	Period	Rainfall (mm)	Δ S (mm)	Runof (mm)	Percolation (mm)	Ro + P + Δ S (mm)	ETa (mm)	ETa (mm/day)
2	27-Dec-18	15.56	13.21	0.04	0.00	13.25	2.31	2.31
5	30-Dec-18	12.45	0.81	1.77	0.00	2.58	9.87	3.29
11	5-Jan-19	15.90	-0.62	0.07	0.00	-0.55	16.45	2.74
20	14-Jan-19	14.31	-4.56	0.04	0.00	-4.53	18.84	2.09
24	18-Jan-19	18.67	4.31	3.67	0.00	7.98	10.69	2.67
27	21-Jan-19	13.69	0.20	3.46	0.00	3.66	10.03	3.34
34	28-Jan-19	0.62	-19.72	0.00	0.00	-19.72	20.35	2.91
41	4-Feb-19	31.12	12.57	3.78	0.00	16.35	14.77	2.11
50	13-Feb-19	39.21	7.17	6.33	0.00	13.49	25.72	2.86
54	17-Feb-19	31.43	1.57	14.51	0.00	16.08	15.35	3.84
58	21-Feb-19	55.77	-1.23	42.19	0.00	40.96	14.81	3.70
62	25-Feb-19	63.38	0.11	51.86	0.00	51.97	11.41	2.85
67	2-Mar-19	32.05	-0.16	21.04	0.00	20.87	11.18	2.24
71	6-Mar-19	45.43	0.13	30.44	0.00	30.56	14.87	3.72
Average (mm/day)								2.91

Source: Results of primary data analysis.

Table 5. Crop Evapotranspiration (ETa) values for end stage

Days to-	Period	Rainfall (mm)	Δ S (mm)	Runoff (mm)	Percolation (mm)	Ro + P + ΔS (mm)	ETa (mm)	ETa (mm/day)
2	27-Dec-18	15.56	11.71	0.09	0.03	11.84	3.72	3.72
5	30-Dec-18	12.45	0.55	0.06	0.10	0.71	11.74	3.91
11	5-Jan-19	15.90	-6.43	0.16	0.18	-6.08	21.98	3.66
20	14-Jan-19	14.31	-17.16	0.00	0.07	-17.08	31.40	3.49
24	18-Jan-19	18.67	3.14	0.00	0.08	3.22	15.45	3.86
27	21-Jan-19	13.69	2.54	0.00	0.17	2.70	10.99	3.66
34	28-Jan-19	0.62	-22.04	0.00	0.08	-21.97	22.59	3.23
41	4-Feb-19	31.12	4.97	0.00	0.07	5.03	26.08	3.73
50	13-Feb-19	39.21	7.35	0.00	0.05	7.40	31.81	3.53
54	17-Feb-19	31.43	12.69	0.00	0.14	12.83	18.60	4.65
58	21-Feb-19	55.77	16.18	23.90	0.15	40.23	15.53	3.88
62	25-Feb-19	63.38	-0.65	47.74	0.15	47.24	16.15	4.04
67	2-Mar-19	32.05	-0.28	13.06	0.19	12.97	19.08	3.82
71	6-Mar-19	45.43	0.57	27.74	0.15	28.45	16.99	4.25
Average (mm/day)								3.82

Source: Results of primary data analysis.

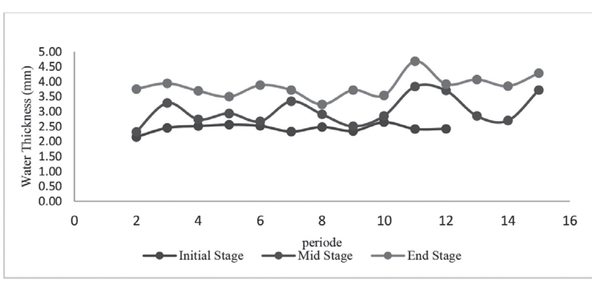

Fig. 9. Evapotranspiration pattern of sago palm in three growth stages

Crop Coefficient Value of Sago Palm (Kc)

The comparison of the evapotranspiration value and the value of the crop coefficient (Kc) in the initial-season of growth, the mid-season and the end-season can be seen in Figure 10.

Discussion

Figure 4 shows that the highest ETo value occurred in October (4.68 mm / day) and the lowest in June (2.95 mm / day). Table 1 shows that the high ETo value in October was caused by two factors, namely

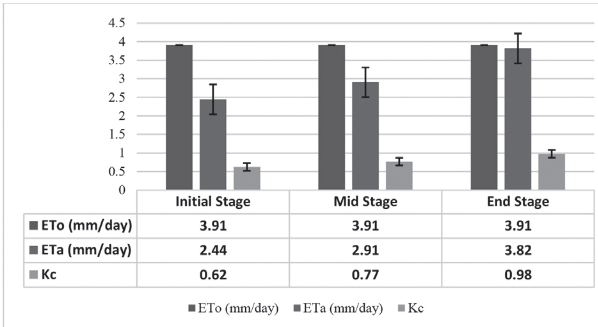

Fig. 10. Crop coefficient values (Kc), standard evapotranspiration (ETo), and crop evapotranspiration (ETa) in the three stages of sago palm growth.

the soaring solar radiation (21.1 MJ / m / day) and the exposure time reaching 7.5 hours per day. The effect of solar radiation and irradiation time on ETo values has also been proven by Li *et al.* (2017) in his research in China on evapotranspiration responses to climate factors. Solar radiation and long irradiation cause high ETo because both climate parameters are energy suppliers to the process of plant metabolism (Didari and Ahmadi, 2019). Vice versa, low and brief irradiation causes low ETo values as shown in June ETo values (Table 2). The low level of solar radiation reaching the surface of the earth or plants can be caused by other climatic factors such as the condition of the clouds in the atmosphere (Jiang *et al.,* 2019). Table 1 shows that the low ETo value is not only caused by the factors of solar radiation and short irradiation but is also caused by the low wind speed which is only around 95 km/day. These parameters have been tested by Ferreira *et al.* (2019) in conjunction with standard evapotranspiration (ETo). The degree of correlation between climatological factors and standard evapotranspiration at the research site is clearly seen in the correlation coefficient (r) (Fig. 5). The humidity factor shows an inverse relationship with ETo values. Standard evapotranspiration values tend to decrease if humidity is high (Jhajharia *et al.,* 2015).

Sago palm evapotranspiration shows different values at each growth phase. Evapotranspiration tends to increase as plants age. Table 3 shows the average ETa values for the initial stage of growth were 2.44 mm/day, the mid stage 2.91 mm / day (Table 4), and the end stage increased to 3.84 mm / day (Table 5). Differences in ETa values correlate with canopy changes (Alam *et al.,* 2019) and plant root conditions as important components in the process of water absorption and plant water use (Wu *et al.,* 2019). The amount of evapotranspiration is very dependent on the energy supply from the sun, steam pressure, and wind. In addition to factors in the atmosphere, soil factors, and their contents, also affect the rate of evapotranspiration, including standing water (Yu *et al.,* 2019), salinity (Marino *et al.,* 2019), organic matter, texture, and density soil.

Figure 9 shows the evapotranspiration pattern of sago palm in three growth stages. The initial phase has a lower evapotranspiration value and the pattern tends to be stable from the beginning to the end of the observation. The mid stage and the end stage show a rather wavy pattern. That is, that there is a period of stable water absorption and there are periods that increase or decrease dramatically from other periods. The pattern is inseparable from the distribution of various factors driving evapotranspiration such as sunlight, wind, temperature, including plant internal factors such as stomata, in response to external factors (Buckley, 2019).

Crop coefficients (Kc) (Fig 10) in the three growth phase sampling show a tendency to increase with increasing plant age. The initial stage with the value of Kc 0.62, the mid stage 0.77, and the end stage 0.98. These results indicate that the water needs of sago palm also increase with the increasing age of the plant (Seidel *et al.,* 2019). Kc value is influenced by two variables, namely the standard evapotranspiration value (ETo) and actual crop evapotranspiration (ETa). This means that all components that affect ETo and ETa automatically also affect the Kc value. The ETo value becomes reference evapotranspiration determined based on local climatic conditions such as temperature, humidity, wind speed, exposure time, and solar radiation (Allen *et al.,* 1998). Whereas ETa is influenced by other than climate factors, also soil factors such as salinity, soil moisture availability in the root zone, and the response of plants themselves to the availability and lack of water (Mawardi, 2016). Plant response to water is determined by plant morphology such as increasing canopy size, size, and number of leaves (Wang *et al.,* 2019).

Conclusion

The standard evapotranspiration (ETo) value at the study site was 3.91 mm/day. Sago palm evapotranspiration (ETa) is different in each growth stage, (initial stage 2.44 mm / day, mid stage 2.91 mm /

day, and end stge 3.82 mm/day). The ratio of ETo to ETa produces the value of the sago palm crop coefficient (Kc) in the initial stage of growth that is 0.62, the mid stage of 0.77, and the end stage of 0.98. The sago Kc value is the determinant variable of the sago palm water needs and is the basis for establishing sago land water management strategies if it is developed on rainfed dryland.

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