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Assessment of Rice Water Requirement by Using CROPWAT Model in Sumbawa Regency, West Nusa Tenggara, Indonesia

Ieke Wulan Ayu[1*], Husni Thamrin Sebayang[2], Soemarno[3] and Sugeng Prijono[3]

[1]*Doctoral Program of Agricultural Sciences, Faculty of Agriculture, University of Brawijaya, Indonesia*

[2]*Department of Agronomy, Faculty of Agriculture, University of Brawijaya, Indonesia*

[3]*Department of Soil Science, Faculty of Agriculture, University of Brawijaya, Indonesia*

[*]**Corresponding Author:** Ieke Wulan Ayu, Doctoral Program of Agricultural Sciences, Faculty of Agriculture, University of Brawijaya, Indonesia, Tel: (0341)551665; E-mail: iekewulanayu002@gmail.com

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Abstract

Climate change causes pressure on dry land ecosystems, due to limited water availability. The purpose of this research is to assess the water requirement of rainfed rice using Cropwat model in the Unter-Iwes Subdistrict, Sumbawa. The Cropwat 8.0 model with monthly meteorological data input from 2005-2016 in the Sumbawa Regency was used to calculate evapotranspiration, crop water requirements and moisture balance, allowing for adjustment of planting time and evaluation of crop production under dryland conditions. Results showed that the increase in temperature and decreased rainfall can increase the water requirement of rainfed rice plants in the study location. The realization of planting in November (rainy season) requires water at an early stage of plant growth of about 251.9 mm, and can be met from rainfall with a yield reduction risk of 0%. Planting realization conducted in May increase the risk of crop yield reduction, caused by decreased rainfall during the growth period, with a yield reduction of 59.7%.

Keywords: Rice; Water use optimization; Dry land

Introduction

Climate change has become a strategic issue and serious concern in recent years, as it creates pressure on the entire ecosystem [1], and continues to flourish during the twenty-first century [2-4]. The hydrologic cycle becomes more intensive and affects the amount and occurrence of rainfall, especially in dryland farming areas whose productivity is limited by water availability [5,6], and this has an impact on food production and community food security [7].

Sumbawa Regency is one of the districts with the largest dryland crops in West Nusa Tenggara (86.494 Ha) [8]. Sumbawa Regency Agricultural District (2012) explains that in 2010, extreme drought that occurred as a result of the El Nino phenomenon, resulting in crop damage and yield losses, especially rainfed rice. Sumbawa Regency Agriculture Agency (2017) showed that there was a decrease of rice production from (480,924 tons) in 2015 to (432,729 tons) in 2016 (BPS Kabupaten Sumbawa) [8]. Climate change has a strong influence on weather patterns and significantly affects crop yield globally [9].

The decrease of production impacts on dryland rice (upland rice) in Sumbawa regency. The gogo is a local Varieties of Sumbawa, being the main crop grown by lowland to medium dryland farmers, aged 110-120 days with red rice color. Protection of local Sumbawa rice species from extinction is done by planting for generations by the community, because it is resistant to pests and diseases. Upland rice is mostly planted in the fields during the rainy season, as it is prone to drought. Uneven distribution of low-intensity rain greatly affects rice production, and will eliminate the presence of local Sumbawa crops.

Rain is the main source of water in tropical dryland [10], plays an important role in growth and production and yields [11-15]. The low rainfall causes water scarcity, so that plant species and indices of crops are more limited [16]. Down water availability is a serious threat faced by rice cultivation in dry land, resulting in farming cannot be done throughout the year, with the cropping index (IP) less than 1.50 [17]. Water scarcity can reduce ecosystem services in dryland, causing crops to die and land degradation [18,19]. The water deficit reduces the size of plants and grain yields [20]. Rice crops damaged by drought are higher than flood damage and plant pest organism attack [21]. Rice is most vulnerable to extreme climatic events associated with El Nino [22]. The production decline strongly affects the lives of farmers who are entirely dependent on crops especially in remote areas [23,24].

Calculation of water demand and irrigation scheduling is very important in dry land, especially helping farmers in placing the plant growth phase when groundwater availability is sufficient for crop needs. Understanding crop water requirements is essential for scheduling and selecting irrigated cropping patterns in specific areas [25]. The calculation of crop water requirements and evapotranspiration can be used for irrigation schedule planning under varying water supply conditions and reduced yields of various conditions [26]. Several studies on crop water requirements have been conducted [27-31].

Simulation of the soil-plant model can be an economically and environmentally feasible tool in evaluating soil conservation practices. Cropwat 8.0 is a computer model to estimate water demand, and water supply schedule [29]. The Cropwat model is used to estimate crop water requirements and future crop irrigation needs under various conditions [32,33]. Adjustment of site-specific agroecological conditions through upland rice management is a very basic capital valuable for the agricultural development of the food crop sector in support of the national food self-sufficiency program. The objective of this research is to know the water requirement of rice plants in dry land and the effect of decreasing the availability of soil moisture on crop production.

Materials and Method

The study was conducted in Unter Iwes Sub-district, Sumbawa District, West Nusa Tenggara Province (NTB), and Indonesia from March 2015-December 2017. Geographically, it is in position 8°32.5, 5 'LS to 8°32.315' LS and 117°24.51, 8 'BT to 117°26.312' BT; the data used in the research is meteorological data for the period of 2005-2016 from BMKG data of Sumbawa Regency. The calculation of the water balance using Cropwat 8.0 is a decision support software developed by

FAO with climate data input data (maximum temperature, minimum, humidity, wind speed, and duration of irradiation) (Table 1). The effective rainfall calculation uses the USDA soil conservation service method (Table 2). The soil data used were derived from soil samples collected from several sites in the root zone with the brown mediteran complex and mediteran brownish reddish-brown Mediterranean soils (Table 3). Plant data (Table 4) is taken from the Cropwat 8.0 Database that is adapted to most cultivated plants.

Estimates of evapotranspiration were analyzed using FAO-Penman Monteith on Cropwat 8.0 model [34].

Month	Min Temp(°C)	Max Temp(°C)	Humidity (%)	Wind (km)	Sun (hours)	Radiation (MJ/m^2/day)	ETo (mm/day)
Jan	22.0	32.6	85	10	4.5	14.6	3.04
Feb	22.3	32.3	86	10	5.1	16.4	3.39
Mar	21.7	32.9	85	10	4.6	16.4	3.44
Apr	22.3	33.8	81	8	6.0	18.7	3.91
May	21.5	33.9	78	8	6.9	19.6	4.03
Jun	20.5	33.4	75	10	7.2	19.6	3.93
Jul	19.2	33.2	72	10	7.2	19.7	3.86
Augt	19.1	34.1	69	11	7.5	20.7	4.02
Sept	20.2	35.9	68	10	7.6	21.0	4.17
Oct	20.9	36.5	70	10	7.5	20.1	4.07
Nov	22.1	36.2	75	9	6.8	18.0	3.71
Dec	22.8	34.6	83	8	5.2	15.2	3.23
Average	21.2	34.1	77	9	6.3	18.3	3.73

Table 1: Estimation of ET_o FAO-PM Period Year 2005-2016 in Sumbawa District.

The effective rainfall calculation uses the "USDA soil conservation service method"

P_{eff} = Pmonth x (125-0.2 x Pmonth) / 125 for Pmonth<250mm

P_{eff} = 125 + 0.1 x Pmonth for Pmonth>250mm

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma \dfrac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where ET_0 = reference evapotranspiration (mm/day), Rn = net radiation at the crop surface (MJ·m−2·day−1), G = soil heat flux density at the soil surface (MJ·m−2·day−1), T = mean daily air temperature at 2m height (˚C), u2 = wind speed at 2 m height (m·s−1), e_s = saturation vapor pressure (kPa), e_a = actual vapor pressure (kPa), e_s- e_a = saturation vapor pressure deficit (kPa), Δ = slope of saturation vapor pressure versus air temperature curve (kPa·˚C−1) and γ = psychometric constant (kPa·˚C−1).

The plants evaluated were rice crops, with the first simulated planting date in November. After the required input data were entered, the Cropwat 8.0 model can calculate in every decade: (1) plant coefficient, (2) plant evapotranspiration, (3) effective rain, (4) crop water requirements and (5) percolation.

The moisture balance on the soil can be calculated by the equation:

$SMD_t = SMD_{t-1} + ETC - PE - IR + RO + DP$

Where SMD_t and SMD_{t-1} are soil moisture depth (mm) in periods t and t-1, ETC is the actual evapotranspiration (mm), PE is effective rain (mm), IR is irrigation thickness (mm), RO is runoff (mm), DP is percolation in (mm).

Month	Rainfall (mm)	Effective rainfall (mm)
Jan	241.0	148.1
Feb	285.1	153.5
Mar	203.0	137.1
Apr	39.0	108.1
May	61.7	55.6
Jun	26.2	25.1
Jul	17.4	16.9
Augt	1.7	1.7
Sept	17.1	16.6
Oct	38.4	36.0
Noc	112.5	92.3
Dec	192.3	131.1
Total	13354	924.1

Table 2: Estimation of the Effective Rainfall 2015-2016.

Source: Primary Data (2017).

Parameter	Value
Texture	Medium
Total moisture available	140 mm/m
Maximum infiltration rate	40 mm/m
Maximum depth of roots	1 m
Availability of initial moisture	140 mm/jam

Table 3: Soil Characteristics Used in Simulation Analysis.

The reduction of crop yield in each phase and its cumulative can be calculated by the formula:

$$\left(1-\frac{Ya}{Ym}\right)=Ky\left(1-\frac{ETa}{ETm}\right)$$

$$\left(1-\frac{Ya}{Ym}\right)=1-\left(\frac{Ya}{Ym}\right)_1*\left(\frac{Ya}{Ym}\right)_2*\dots*\left(\frac{Ya}{Ym}\right)_i$$

(i = crop growth stages; K_y = yield reduction factor; Y_a and ET_a = actual yield and actual ET; Y_m and ET_m = maximum yield and maximum ET).

Results and Discussion

The results showed that the ET_o value fluctuated from 3.04 mm/day (January) - 4, 17 mm/day (September). Decrease in ET_o values began to occur in October (4.07 mm /day) be (3.71 mm/day) in November, and 3.23 mm /day in December. The decline in ET_o values occurs as rainfall increases. Changes in meteorological factors (temperature, humidity, wind speed, solar irradiance and radiation) correlate linearly to changes in ET_o value [35]. Projected temperatures and precipitation vary geographically and latitudinal show different results for tropical dryland [3,36]. Rainfall in Indonesia will increase during the rainy season and decrease during the dry season [37].

The average rainfall that falls in the region of Sumbawa Regency is 1335.4 in the period 2015-2016, with effective rainfall of 924.1 mm. The increase in rainfall began in September (17.1 mm), rising to 38.4 mm in October, November (112.5 mm), up to February (285.1 mm), and beginning to decline in March (203.0 mm) .The rainy season lasts from November to March, and the dry season runs from May to September, while October becomes the transition month [38]. Temperature and rain changes may be the cause of reduced water availability in soil due to a strong correlation with the amount of water lost through evapotranspiration [39], impacting changes in planting date [40].

Crop	Indicator	Crop Growth Stages:				Total
		I	II	III	IV	
Rice	Growth Stage(day)	30	45	70	30	150
	Kc	0.70	0.80	1.05	0.70	0.80
	Ky	0.80	0.80	0.80	0.80	
	Root zone (m)	>>>	>>>	0.10	0.60	
	Deplecion (p)	0.20	>>>	0.40	0.20	

Table 4: Crop Growth Stages and its Indicators.

Data sources: Database Cropwat for Windows.

Based on the amount of precipitation that occurs then November is a potential month for the determination of planting time, with rainfall that has exceeded >50 mm. Penentuan early planting potential is done if the rainfall has exceeded 35 mm/dasarian for three consecutive dasarians starting in September [41]. The beginning of MH as an incident three times dasarian rain > 50 mm sequential so that the entry of the beginning of the rainy season is the first dasarian where rain > 50 mm [42]. The timing of planting should be based on climatic conditions, especially rainfall, so that plants can obtain water for growth and production [43]. Result of calculation of crop water requirement with method of Cropwat 8.0., in months with high effective rainfall indicates variation in moisture balance and production reduction (Table 5).

Date Planting	Date of Harvest	Effective Rainfall (mm)	ETc (mm)	Crop water requirement (mm)	ETc/ETm (%)	Eta (mm)	ETp (mm)	SMD End (mm)	Crop Yield Reduction (%)
11 Nov	10 Mar	600,9	523,3	251,9	100	400,9	400,9	1,5	0,0
11 May	7 Sept	170,3	621,2	681,4	40,3	183,4	402,4	1,5	59,7

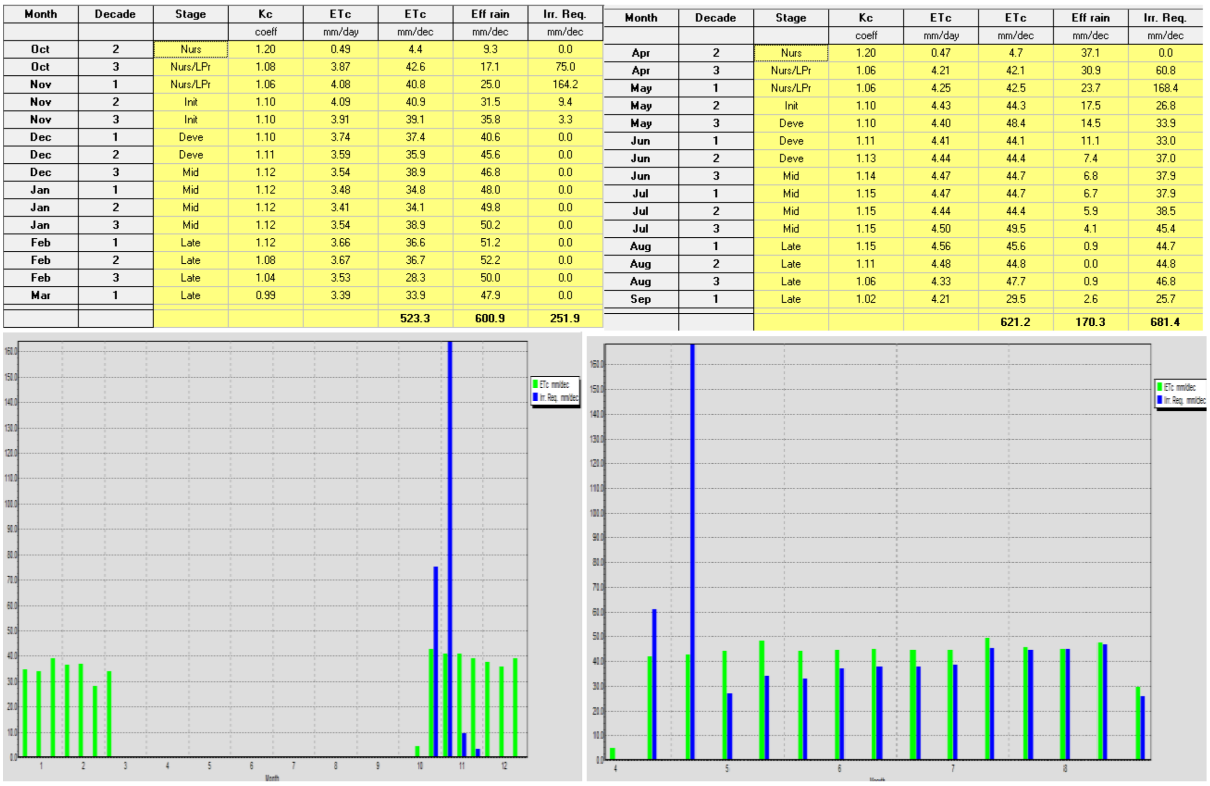
Table 5: Availability of soil moisture in different season.

SMD: Soil Moisture Deficit

The planting on November 1 (rainy season) has the safest reduction of 0.0 %, compared to planting on May 1 (dry season) of 59.7%, due to the availability of soil moisture affected by soil conditions that store water for crop water requirements. Inadequate soil conditions permeate surface waters and store water available for crops from rainfall, affect moisture stores in plant rooting, with increased evapotranspiration [14,44,45].

Figure 1 shows that ET_c on November 1st (rainy season) planting during the growth period of 523.3 mm /dec higher, compared to planting on dasarian-1 May (dry season) (621,2 mm/dec). Planting in the rainy season requires water in the early stages of plant growth of about 251.9 mm to meet the water requirement at the vegetative stage

(0-60 days) that can be met by the availability of water from rainfall (Figure 2). Effective rainfall can neutralize the increase in water needs of plants [46]. In contrast to planting in the dry season requiring water at each stage during its growth, starting in the vegetative phase (0-60 days), generative phases (60-90 days), and cooking (90- 120 days). Rice plants began to consume a lot of water during the period of growth. Water requirements in the three phases varied in the active tillering phase, maximum tiller, initiation of panicle formation, pregnancy phase and flowering phase. The water requirement of rice plants decreased linearly from 168.4 mm to 26.8 mm at the end of the decade in a growth phase where demand for maximum water to grow. Then, it increases from 33.9 mm to 46.8 mm at the beginning of the mid-stage stage where the rice crop consumes a lot of water to grow and reach its maximum height. In the final stages of growth, the rice crop water requirement decreases linearly from 46.8 to 25.7 mm.



Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	2	Nurs	1.20	0.49	4.4	9.3	0.0
Oct	3	Nurs/LPr	1.08	3.87	42.6	17.1	75.0
Nov	1	Nurs/LPr	1.06	4.08	40.8	25.0	164.2
Nov	2	Init	1.10	4.09	40.9	31.5	9.4
Nov	3	Init	1.10	3.91	39.1	35.8	3.3
Dec	1	Deve	1.10	3.74	37.4	40.6	0.0
Dec	2	Deve	1.11	3.59	35.9	45.6	0.0
Dec	3	Mid	1.12	3.54	38.9	46.8	0.0
Jan	1	Mid	1.12	3.48	34.8	48.0	0.0
Jan	2	Mid	1.12	3.41	34.1	49.8	0.0
Jan	3	Mid	1.12	3.54	38.9	50.2	0.0
Feb	1	Late	1.12	3.66	36.6	51.2	0.0
Feb	2	Late	1.08	3.67	36.7	52.2	0.0
Feb	3	Late	1.04	3.53	28.3	50.0	0.0
Mar	1	Late	0.99	3.39	33.9	47.9	0.0
					523.3	**600.9**	**251.9**

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	2	Nurs	1.20	0.47	4.7	37.1	0.0
Apr	3	Nurs/LPr	1.06	4.21	42.1	30.9	60.8
May	1	Nurs/LPr	1.06	4.25	42.5	23.7	168.4
May	2	Init	1.10	4.43	44.3	17.5	26.8
May	3	Deve	1.10	4.40	48.4	14.5	33.9
Jun	1	Deve	1.11	4.41	44.1	11.1	33.0
Jun	2	Deve	1.13	4.44	44.4	7.4	37.0
Jun	3	Mid	1.14	4.47	44.7	6.8	37.9
Jul	1	Mid	1.15	4.47	44.7	6.7	37.9
Jul	2	Mid	1.15	4.44	44.4	5.9	38.5
Jul	3	Mid	1.15	4.50	49.5	4.1	45.4
Aug	1	Late	1.15	4.56	45.6	0.9	44.7
Aug	2	Late	1.11	4.48	44.8	0.0	44.8
Aug	3	Late	1.06	4.33	47.7	0.9	46.8
Sep	1	Late	1.02	4.21	29.5	2.6	25.7
					621.2	**170.3**	**681.4**

Rainy season (11th November)

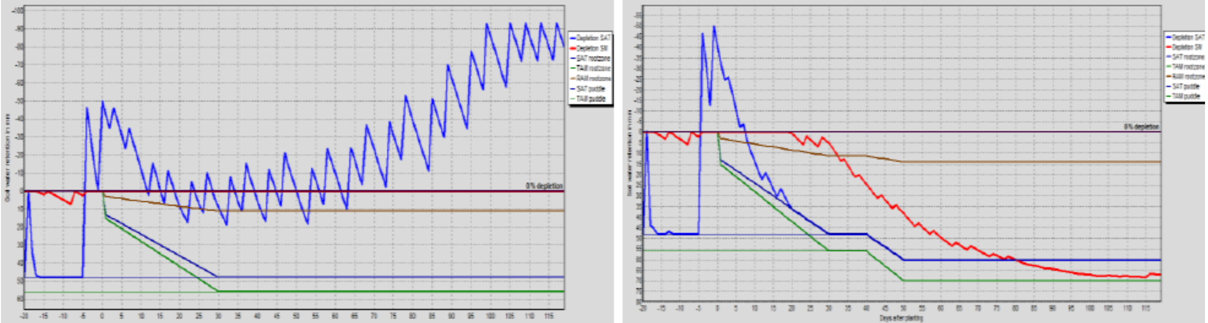
Dry Season (11th May)

Figure 1: Rainy season (11th November), Crop water requirement and irrigation requirement of upland rice plants in the dryland.

Figure 2 planting in the dry season require almost the same irrigation needs for crop water requirements due to reduced water availability due to reduced rainfall and increased ET_0. Withdrawal of planting time will increase pressure on plants due to decreased availability of moisture [14]. Planting and planting seasons are based on sufficient water index indicators, known as the actual evapotranspiration (ET_a) and plant evapotranspiration (ET_c) [47]. Temperature and precipitation have an important role with the fulfillment of the necessary water requirements as a body-building material, water shortage in plants causes growth to be inhibited so that the production is not optimal [48,49]. Due to lack of precipitation will result in reduced productivity [50]. Drought on ecosystems in dryland affects the soil moisture [1]. The realization of cultivation done in May, may increase the risk of crop yield reduction, caused by high rainfall in the early period of growth be able to meet the water requirement during the period growth, with a risk of 59.7%. Each plant has a critical period of different water pressures [51]. Song et al. [52] shows that rice cultivation in the dry season requires additional irrigation water. The amount and distribution of rain and soil properties in water holding affect the duration of the land can be cultivated (growing season) on dry land [43]. Implementation of the suitable rice cropping patterns is one way to minimize effects of the soil moisture deficit. The suitable plant patterns and irrigation schedules are one of the most efficient strategies in reducing water deficits [53].

Conclusion

Evaluation shows the tendency of variability of moisture balance as appropriate when planting. ET_C is highly determined by the capacity of groundwater storage and the amount of rainwater infiltrated into the soil. The water requirement of crop and the soil moisture balance are very important as a consideration in selecting the suitable cropping model, so as not to experience a significant crop yield reduction due to the limited availability of soil moisture during the crop growing season.



Availability of Soil Moisture in Rainy Season (11th November)

Availability of Soil Moisture in Dry Season (11th May)

Figure 2: Crop Water Requirements and Availability of Soil Moisture in Rooting Zone.

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