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The Impact of Climate Change on Crop Water Requirement for Crops on Dryland Area: A Case Study for Coffee Plantation in Sumbermanjing Wetan

Yogi Pasca Pratama[1,2], Hurng-Jyuhn Wang[3], Doo-Chul Kim[4], Chun-Hung Lee[5], Lina Saraswati[6]

[1]Faculty of Economics and Business, Sebelas Maret University, Surakarta, Indonesia, 57126
[2] Ph.D. Program in Asia-Pacific Regional Studies, National Dong Hwa University, Shoufeng, Taiwan (R.O.C), 97401
[3]College of Humanities and Social Sciences, National Dong Hwa University, Shoufeng, Taiwan (R.O.C), 97401
[4]Graduate School of Environmental and Life Science, Okayama University, Okayama, Japan, 700-8530
[5]College of Environmental Studies, National Dong Hwa University, Shoufeng, Taiwan (R.O.C), 97401
[6]Soil Laboratory of the Faculty of Agriculture, Brawijaya University, Malang, Indonesia, 65145
Email address: [1]yogipasca@staff.uns.ac.id; [2]hongjinwang@gmail.com, [3]kim@okayama-u.ac.jp; [4]chlee@gms.ndhu.edu.tw; [5]linasusilo98@gmail.com

Abstract—*Sumbermanjing Wetan area has the potential for coffee production, but changes in rainfall patterns and climate can impact water availability for coffee plants. Therefore, it is important to assess the water needs of coffee plants in order to understand their resilience to climate changes, optimize water usage, and increase productivity. This study aimed to evaluate the water needs of coffee plants in Sumbermanjing Wetan and analyze the issues related to water availability and climate change that affect coffee production in the area. The study found that the water needs of coffee plants were not being met due to low effective rainfall. This resulted in a decrease in soil moisture content during the crucial growth phase of coffee plants, leading to a decline in coffee production by 11.4% in the 1998-2018 period and 15.8% in the 2019-2021 period.*

Keywords— *Climate Change, Coffee, Crop Water Requirement, Sumbermanjing Wetan.*

I. INTRODUCTION

Coffee production as an important agricultural commodity faces increasingly complex challenges due to climate change. The Sumbermanjing Wetan region has long been considered one of Indonesia's main coffee farming centers. Coffee production is very important to the local economy. But the sustainability of coffee farming is a complex challenge that requires innovative solutions in the midst of increasingly worrying global climate change (Pham, et al. 2019).

In the context of this area, effective water management is an important issue. Water availability fluctuates and is unpredictable due to increasing temperatures, changes in rainfall and erratic wind patterns. To overcome this problem, soil and water conservation and the use of the latest technology are very important for the sustainability of sustainable coffee production (Toledo and Moguel 2012). Jiyanti, Prijono and Prasetya (2021) investigated the impact of climate change on water supplies in Sumbermanjing Wetan. This research analyzes the variable moisture, transpiration rate, soil water potential, leaf water potential, and microclimate, especially temperature and sunlight intensity. The climate in the study area is only divided into dry and rainy seasons, but it is this dynamic of change that researchers want to explore. The decrease in transpiration rate is found during the transition season from summer to rainy season, and vice versa. This changing microclimate also drives changes in the transpiration factor, which can be said to have changed a lot is the intensity of sunlight and temperature.

As a result of the impact of climate change, coffee farming in Sumbermanjing Wetan is undergoing an increasingly rapid and complex transformation. Events such as unexpected rainfall, extended dry seasons, and extreme temperature spikes have become more common. All of these changes affect water availability, and planning planting and harvesting becomes more difficult for farmers. Ty, et al. (2012) examine the evaluation of coffee crop water requirements under various climate scenarios. This article provides valuable insight into how coffee production can be affected by changing weather and different rainfall patterns. In addition, comprehensively examines the impact of climate change on coffee production. This review provides an in-depth understanding of the challenges faced and the changes that are likely to occur under different climate scenarios (Jawo, Kyereh and Lojka 2022).

Management of water resources is very important. Soil and water conservation is needed in every agricultural process, this needs to be done to achieve efficiency and effectiveness in the use of water resources. Bracken, Burgess and Girkin (2023) conducted a review of sustainable resource management practices. This article reveals that climate change can affect coffee production both in terms of quantity and quality. The outcomes reviewed in relation to climate change in this article are the increasing intensity and frequency of extreme climate events, crop yields, quality of coffee produced, reduced production, to an increased potential for the development of plant diseases and other pests.

To respond to climate change that is happening and the potential losses that will result, and as an effort to overcome this problem, the Food and Agriculture Organization of the United Nations (FAO) developed a scientific-based water management application called Cropwat 8. With this application, the goal of increasing the effectiveness and suitability of water management can be achieved, especially in coffee farming. This research is important for both the interests of farmers and related stakeholders. The extreme dynamics of climate change cannot be controlled by humans, but scientifically it is possible to calculate plant demand patterns from long climate data. The purpose of this research is to contribute to water management in dry land, especially in the study location to support existing coffee plantations.

II. MATERIAL AND METHODS

A. Input Data

This simulation was carried out on coffee plants in the Sumbermanjing Wetan area, Malang Regency, which is located at 8o 16'54.2 "S 112° 41'03.3" East Longitude. The Sumbermanjing Wetan area is located at an altitude of 598 above sea level. This simulation was carried out in 2 different periods, in the period 1998-2018 and the period 2019-2021. The climate data used for the Cropwat 8 simulation in this study used climate data from the Karangkates observation station (Table 1 and 2). The soil data used in this simulation uses the FAO database, the soil type used is medium (Table 3). Meanwhile, coffee plant data is presented in Table 4, with the specified planting date July 1.

TABLE I. Climate data for the period 1998-2018.

Components	T_{min} (^{0}C)	T_{max} (^{0}C)	Humidity (%)	Wind speed (km.day^{-1})	Day length (%)	Rainfall (mm)
January	22.3	31.4	85	89	41	323
February	22.1	31.3	84	101	40	338
March	22.0	31.8	85	99	48	268
April	22.1	32.0	83	95	55	231
May	21.7	31.8	81	95	62	116
June	20.7	31.3	80	108	63	73
July	20.0	30.8	79	126	65	30
August	19.7	31.0	77	136	68	13
September	20.7	32.0	76	127	66	42

TABLE II. Climate data for the period 2019-2021.

Components	T_{min} (^{0}C)	T_{max} (^{0}C)	Humidity (%)	Wind speed (km.day^{-1})	Day length (%)	Rainfall (mm)
January	22.7	31.2	86	68	33	350
February	22.9	31.5	85	69	56	235
March	22.7	31.7	86	71	60	382
April	22.7	32.3	83	74	76	187
May	22.5	32.0	81	88	85	127
June	21.1	31.5	81	82	83	82
July	20.8	30.6	78	116	84	15
August	20.8	30.7	78	133	89	10
September	21.6	31.7	77	120	90	63

TABLE III. Land data.

Parameters	Values
Texture	loam
Total Available Moisture (TAM)	290 mm.m-1
Maximum infiltration rate	40 mm.day-1
Maximum root depth	900 cm
Initial moisture availability	290 mm.m-1

TABLE IV. Plant data.

Parameters	Growth Phase				Total
	I	II	III	IV	
Growth phase (day)	85	85	85	110	365
Kc	1.05	>>>	1.10	1.10	
Ky	1.05	1.05	1.20	1.20	1.20
Root zone (m)	0.90	>>>	1.50	1.50	

B. Analysis

a. The Cropwat 8 application processes meteorological data to estimate potential evapotranspiration (ETo) using the Penman-Monteith equation:

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2VPD}{\Delta + \gamma(1 + 0.34U_2)}$$

Where,
Et_o : Potential evapotranspiration (mm day^{-1})
Δ : Changes in saturated vapor pressure associated with changes in air temperature
Rn : Net radiation ≈ evapotranspiration (mm day^1)
G : Changes in soil temperature storage under saturated conditions
γ : Psychrometer coefficient
T : Air temperature (^{0}C)
U2(VPD) : Wind speed at a height of 2 m above ground level (km.hour^{-1})

b. Effective rainfall (P*eff*) in the study was calculated using the USDA soil conservation service method equation, namely:

$$P_{eff} = P_{tot}\ x\ \frac{125 - 0.2\ P_{tot}}{125}\ ,for\ P_{tot} < 250\ mm$$
$$P_{eff} = 125 + 0.1\ x\ P_{tot}\ ,for\ P_{tot} > 250\ mm$$

c. Plant water needs (CWR) calculated using the equation: $CWR = ET_o\ x\ K_c$, where ET_o is the potential evapotranspiration and Kc is the coffee plant coefficient value.

d. Total soil moisture (TAM) is calculated using the equation: $TAM = (FC - WP)\ x\ Z_r$, where Fc is moisture at field capacity, WP is moisture at permanent wilting point and Zr is root zone thickness.

e. Available water (RAM) is calculated using the equation: $RAM = TAM\ x\ P$, where p is the soil moisture depletion value.

f. Estimated reduction in coffee plant production is calculated using the equation: $\left(1 - \frac{Y_a}{Y_m}\right) = K_y\left(1 - \frac{ET_a}{ET_m}\right)$, where Y_a is actual production, Y_m is the maximum production, ET_a is the actual evapotranspiration, ET_m is the maximum evapotranspiration and K_y is the production coefficient.

III. RESULTS AND DISCUSSION

A. Temperature trends

There was an increase in maximum temperature in Malang district in the last 3 years compared to the 1998-2018 period (Fig. 1). The maximum increase in temperature occurs in February and April-June. These results are in accordance with the results of the study of Herlina and Prasetyorini (2020) which projects that there will be an increase in air temperature

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in Malang Regency up to 1 ^{0}C in 2030 compared to the 1961-1990 period.

An increase in air temperature affects an increase in soil moisture loss through the evaporation process and an increase in air temperature causes an increase in potential evapotranspiration (ET_o). This is reinforced by the results of the study by Chen, Wei and Liding (2020) which shows that areas with an average air temperature <5 ^{0}C have higher moisture content compared to areas with an average air temperature >15 ^{0}C in the same land conservation practice, namely by making terraces. An increase in potential evapotranspiration (ET_o) due to an increase in air temperature causes a decrease in the availability of moisture for plant growth.

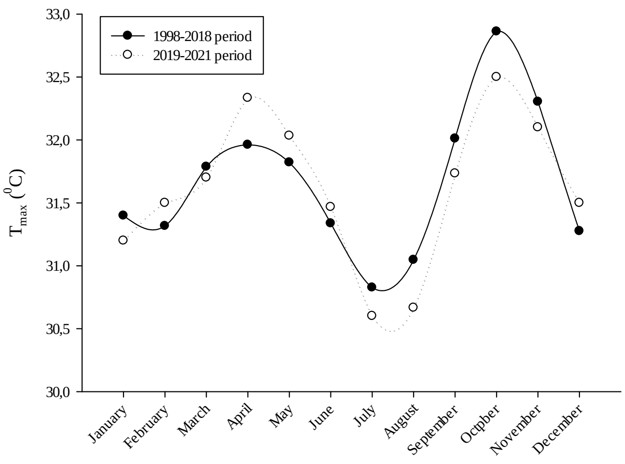

Fig. 1. Temperature trends in Malang district at different observation periods

B. Rainfall trends

High rainfall occurred in December in the 1998-2018 period, while in the 2019-2021 period it occurred in March. Differences in rainfall patterns are also shown by the results of the study by Haditiya and Prijono (2018) where the Karangkates climate station in Malang Regency recorded high rainfall occurring in December during 1998-2016, while in 2014-2016 high rainfall occurred in February.

Rainfall in the 1998-2018 period was lower than the 2019-2021 period, namely 2230 mm in the 1998-2018 period, while in 2019-2021 it was 2127 mm. These results are in accordance with the results of the study of Herlina and Prasetyorini (2020) who projected a decrease in average monthly rainfall in Malang Regency in 2030. Rainfall affects soil moisture in the study location because the study location (Sumbermanjing Wetan area) is classified as dry land.

Rainwater is the only soil moisture input in dry land and is unable to meet crop water needs (Ayu, Prijono and Marno 2013). Therefore, Bana and Prijono (2013) mentioned water as a limiting factor for plant growth and production on dry land. So that the decrease in rainfall in the study locations in the 2019-2021 period is expected to affect the growth and production of coffee plants. Various scientific articles discussing the impact of climate change on coffee farming. Various scientific literature explains the negative impacts of climate change, especially high rainfall which will cause flooding which of course affects coffee yields as well as the development of pests that spread more quickly when the climate changes dynamically. On the other hand, climate change also has a positive impact on the pollination process and increases in carbon concentrations which will also increase crop yields. However, the concentration of this study took many samples in America with Arabica coffee cultivation, and did not take research samples from other continents that concentrated on planting Robusta coffee (Pham, et al. 2019).

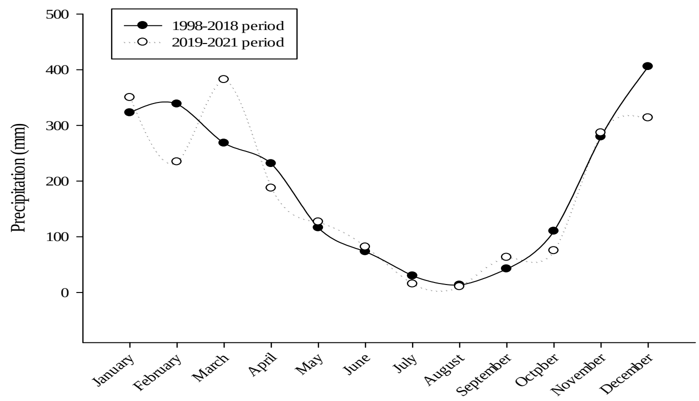

Fig. 2. Rainfall trends in Malang district at different observation periods

C. Potential evapotranspiration (ET_o)

Evapotranspiration is the loss of soil moisture through the soil surface (evaporation) and plant bodies (transpiration). Potential evaporation (ET_o) is evapotranspiration which is solely influenced by environmental factors. Fig. 3 shows the monthly rainfall (mm) and potential evapotranspiration at the study site at different periods. Potential evapotranspiration which is higher than rainfall indicates a decrease in soil moisture availability which is referred to as a deficit month. Conversely, the low potential evapotranspiration compared to rainfall indicates an increase in soil moisture availability, which is referred to as a surplus month.

Fig. 3 shows that potential evaporation is higher than rainfall occurring from June to October both in the 1998-2018 period and in the 2019-2021 period. This shows that from June to October there is a decrease in soil moisture availability. Deficit periods that occur in months where the potential evapotranspiration is higher than rainfall are known to affect the growth and production of coffee plants. According to Supriadi (2014) coffee plants need 2-4 deficit periods to stimulate flowering. The results of his research stated that the deficit period occurred for 5 consecutive months, namely in 1991, 1993, 1994 and 1997 in the Jollong plantation, Pati which caused a decrease in coffee production by 56.35% in 1992, 36.18% in 1994, 41.03% in 1995 and 13.63% in 1998. Strategies for dealing with the impacts of climate change on coffee plants is on efforts to modify the microclimate and water use by having shade trees around the main trees. The main findings of this study is that the success of a microclimate strategy in the presence of shade plants must be

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complemented by an understanding of the location settings and also the types of plants chosen to shade the types of coffee plants cultivated (Rahn, et al. 2018).

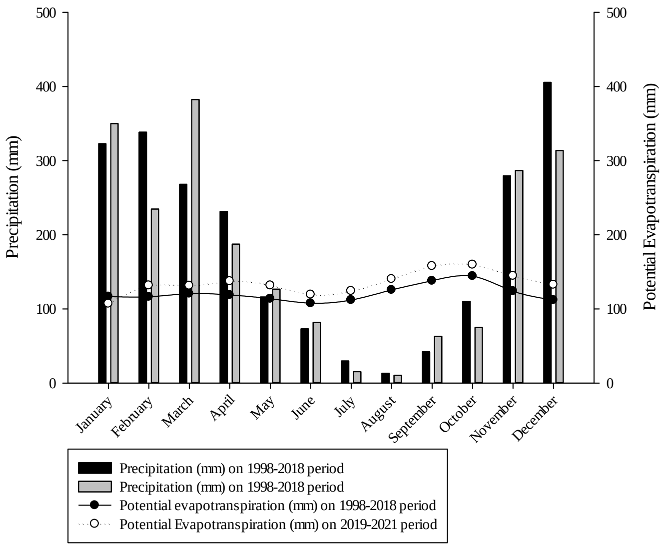

Fig. 3. Rainfall (mm) and potential evapotranspiration (mm) at different periods

D. Plant water requirement (ET$_c$) Coffee

Crop evapotranspiration (ET$_c$) shows the water needs of plants whose value is influenced by potential evapotranspiration (environmental factors) and crop coefficients (crop factors). Fig. 4 shows the monthly coffee plant water requirements in the study locations. Coffee plant water needs in the 2019-2021 period are higher compared to the 1998-2018 period except in January. The water needs of coffee plants in the study locations are thought to be influenced by the potential evapotranspiration value where Fig. 3 shows the potential evapotranspiration in the 2019-2021 period is higher compared to the 1998-2018 period except in January.

The total water requirement of coffee plants in the study locations in the 1998-2018 period was lower than that of the 2019-2021 period, namely 1500 mm.year^{-1} in the 1998-2018 period while in the 2019-2021 period it was 1677 mm.year^{-1}. In the same type of plant, crop water requirements vary according to climate differences. The average water requirement for coffee plants in Indonesia in the period 1995-1999 was 1455 mm.year^{-1}, while in Vietnam it was 938 mm. year^{-1} in the same period (Chapagain and Arjen 2007). The water requirement for Arabica coffee plants is 798.25-1510.33 mm.year^{-1} in Brazil, while in Ethiopia it is 1568 mm.year^{-1} (Ashine 2019).

Plant water needs are influenced by plant factors, where the components that influence besides the type of plant, are also the growth phase of the plant. Fig. 5 shows that the coffee plant's water requirements vary at different growth phases. High plant water needs occur in the ripening phase (late) while low plant water needs occur in the middle phase. The initiation phase is the vegetative development phase, namely the initiation of flower bud formation, development is the development phase of flower buds and flowering, mid season is the phase of fruit formation and development while the late season is the ripening and harvesting stage. The results of Ashine's study also show the low water requirement of the Arabica coffee plant in the initiation phase, while the high water demand of the Arabica coffee plant occurs in the mid-season phase (Ashine 2019).

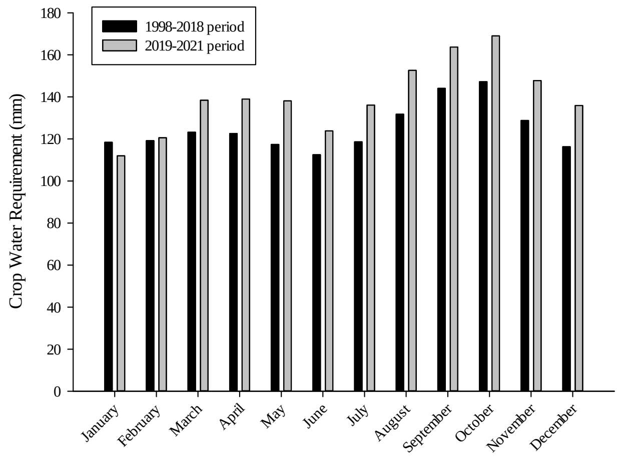

Fig. 4. Monthly coffee plant water requirement (mm) at different periods

Plants need water according to their needs, if the plants do not get enough water then the plants will experience water stress. Water stress that occurs in the critical phase will affect plant growth and production. Coffee plants require adequate soil moisture availability during the fruit development phase to produce large and quality coffee beans. Water stress that occurs during the fruit development phase causes a decrease in the size of the coffee fruit, the coffee fruit skin becomes yellow while the coffee fruit seeds are blacker. In addition, water stress in the mid season can inhibit the growth of branch shoots which has an impact on decreasing coffee plant production in the following year (Carr 2001).

The volume of annual rainfall does not affect the production of coffee plants but the distribution of rainfall in one year has more influence on coffee plant production where the water demand of coffee plants increases during the fruit development phase (Gay, et al. 2006). Surendran, et al. (2015) used the Cropwat model to carry out a water balance analysis. The selected case study is Palakhad District. The projections for the future carried out by this research are water for irrigation needs, drinking water, and water needs for industry. So this research tries to project the deficit that will occur for these three interests, and tries to discuss several scenarios to overcome this.

E. Moisture depletion at the root zone

Soil moisture depletion in the root zone shows the dynamics of soil moisture content in the plant root zone (Fig. 5 and 6). Total Available Moisture (TAM) in the 1998-2018 and 2019-2021 periods is in the moisture retention range of 260 mm-439 mm. Total Available Moisture (TAM) shows the amount of moisture available in the root zone. Total Available Moisture (TAM) conditions were between field capacity and permanent wilting point conditions. After rain, the pore space of the soil will be filled with water until it reaches field capacity, that is, after the drainage process is complete. Plant roots will continue to extract soil moisture so that the soil moisture content decreases until it reaches a permanent wilting point, when water is firmly held by the surface of soil particles and plant roots are no longer able to extract the water. However, before the soil reaches the permanent wilting point, the soil moisture content decreases to a threshold where there is a decrease in the rate of soil moisture extraction by plant roots so that the plants begin to experience water stress. This threshold is Readily Available Moisture (RAM) where if the soil moisture is below the RAM threshold, the plant will experience water stress. In moisture conditions below the RAM threshold, moisture input is needed to increase the soil moisture content above the RAM threshold. Fig. 5 and 6 show that the RAM threshold in the coffee plant root zone at the study site is in the moisture retention range of 102 mm-179 mm.

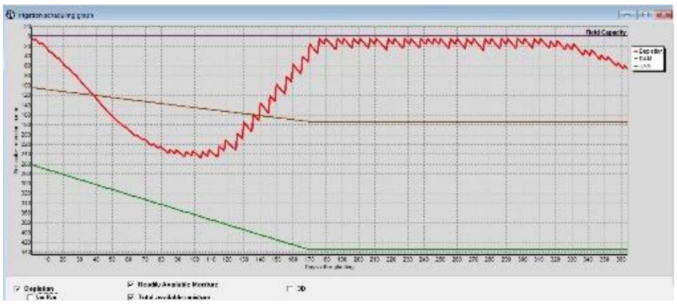

Fig. 5. Moisture depletion in the coffee root zone, 1998-2018

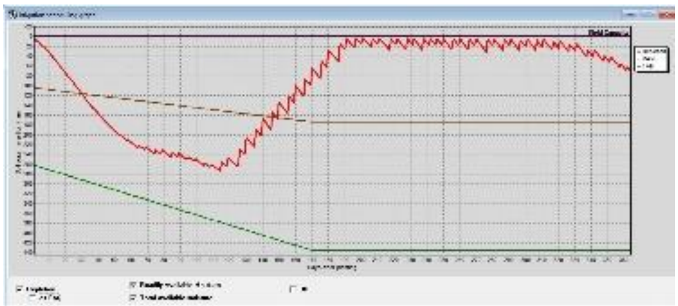

Fig. 6. Moisture depletion in the coffee root zone, 2019-2021

Plants will experience water stress if additional soil moisture input is not given in conditions where moisture decreases below the RAM threshold. There is a difference in the timing of the decrease in moisture and the thickness of the decrease in the root zone of the coffee plant in the 1998-2018 and 2019-2021 periods (Fig. 5 and 6). In the 1998-2018 period, moisture conditions began to decrease below the RAM threshold starting at 40 hst, namely when the moisture retention was 120 mm, the decrease in moisture content continued until 110 hst where the moisture retention was 240 mm, after 110 hst the moisture content then increased. Whereas in the 2019-2021 period, moisture conditions began to decrease below the RAM threshold starting at 30 hst, namely when the moisture retention was 120 mm, the decrease in moisture content continued until 120 hst where the moisture retention was 260 mm, after 120 hst the moisture content then increased. This shows that the water stress that occurred in coffee plants in the study locations during the 2019-2021 period was higher compared to the 1998-2018 period which is thought to affect the growth and production of coffee plants.

F. Potential reduction of coffee plant production

Water stress on coffee plants occurred from 40 hst to 140 hst in the 1998-2018 period, while in the 2019-2021 period water stress occurred from 30 hst to 150 hst. This shows that water stress on coffee plants at the study site occurred in the initiation to development phases both in the 1998-2018 period and in the 2019-2021 period. Water stress affects the decrease in the number of coffee plant branches that water stress causes leaves to fall and branches to die, thereby reducing the number of flower buds and coffee pods (Sumirat 2008). Coffee flower shoots that will develop into coffee fruit are found on productive branches (Rizki, Wijonarko and Purwanto 2020). The results of Rizki et al.'s study shows a correlation between the number of productive branches and coffee production for each plant, which is indicated by a correlation coefficient of 0.928. Therefore, the increase in the potential for reducing production from the results of this study is suspected because the coffee plants in the study area experienced water stress during the growth phase from initiation to development, thereby reducing the number of productive branches of the coffee plant.

TABLE V. Plant water needs and potential reduction in coffee plant production

Component	Period	
	1998-2018	2019-2021
Total rainfall (mm)	2228.0	2127.0
Effective rain (mm)	1463.0	1523.0
Potential evapotranspiration (mm)	1517.4	1672.8
Actual evapotranspiration (mm)	1373.9	1452.0
Production reduction potential (%)	11.4	15.8

The growth and production of the coffee plant is strongly influenced by the sufficient water needs of the coffee plant. Water stress that occurs in the critical plant phase affects the growth and production of coffee plants. Fig. 5 and 6 show that the water stress that occurred in coffee plants in the 2019-2021 period was higher compared to the 1998-2018 period. Therefore, the potential reduction in coffee plant production in the 2019-2021 period is higher compared to the 1998-2018 period (Table 5), namely 15.8% in the 2019-2021 period, while in the 1998-2018 period it was 11.4%.

Legesse (2019) conducted research on the quality of coffee produced, production results, and preventive measures taken to deal with the effects of climate change. The study of the outcome of this study is to see how the amount of production and quality of coffee produced if there are changes or variations in climate patterns. A water footprint study on coffee farming processes in Colombia. This research reveals that using Becolsub© eco-processing will reduce the water footprint by 45.7%, while using Ecomill© eco-processing will reduce the water footprint by 99.9% (Leal-Echeverri and

Tobón 2021). Perry (2014) focuses on criticism of water footprint studies. This article makes sense because this study will not have a direct impact on the locations studied because there are still many hydrological variables that need to be considered. The next thing is that waterfootprint studies are very weak and rarely used as a basis for policy makers both at the regional level and on a national scale, so further understanding of the hydrological cycle is needed which can be physically intervened, and this brings a more holistic understanding of water resources management.

IV. Conclusion

The water demand for coffee plants in the Sumbermanjing Wetan area in the 1998-2018 period was 1500 mm.year^{-1}, while in the period it was 1677 mm.year^{-1}. Effective rainfall in the Sumbermanjing Wetan area in the 1998-2018 period was 1463 mm.year^{-1}, while in the 2019-2021 period it was 1523 mm.year^{-1}. The low effective rainfall in the Sumbermanjing Wetan area compared to the water needs of the coffee plant causes a decrease in soil moisture content below the RAM threshold at the average age of coffee plants from 30 hst to 150 hst, namely the initiation to development phase. This led to an increase in the production reduction potential of 11.4% in the 1998-2018 period, while in the 2019-2021 period it was 15.8%.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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