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Analysis of Reference Evapotranspiration (ETo) and Rainfall on Maize Hybrid Seed Production: Cases in Malang and Jember

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Abstract Maize hybrid seed production cultivation area often has less pollen available than in regular commercial maize because of detasseling to eliminate self-pollination. There are also concerns regarding the increasing intensity of extreme weather following climate change, on top of inherent maize sensitivity to water stress in the flowering period. The objective of this study was to determine the relationship between rainfall, reference evapotranspiration (ETo), and maize hybrid seed yield in two locations using simple regression analysis. Four years of historical weather and harvest data of one type of parental maize line were obtained from Talangsuko, Malang Regency, and Sukoreno, Jember Regency. In conclusion, there was a strong linear and negative relationship between rainfall and the yield of hybrid maize seeds in Talangsuko (R^2=0.60), while in Sukoreno, the relationship was in the form of a quadratic curve (R^2=0.61). In Talangsuko, there was a strong relationship between rainfall in the flowering period and maize yields (R^2=0.60), meanwhile, in Sukoreno, only a few samples experienced rain during the flowering period and consecutive rain so the relationship with maize yields could not be concluded (R^2=0.09 and 0.18). There was no relationship between ETo FAO-56 PM and hybrid maize seed yield (R^2=0.04 and 0.06).

Keywords Hybrid Seed Production, Maize, Flowering, Rainfall, Reference Evapotranspiration

1. Introduction

Maize (*Zea mays* L.) is a cereal crop that can be processed into many types of products. The use of hybrid varieties of maize is one way to increase land productivity. In 2020, 76.87% of maize farmers in Indonesia cultivated hybrid maize varieties, the remaining 17.29% grew local varieties and 5.84% used composite varieties [1]. Hybrid maize is created by cross-pollinating different inbred lines of maize. Hybrid maize breeding includes the development of inbred lines with controlled self-pollination; determination of inbred lines that can be combined into high-yielding crosses; and commercial use of crosses for seed production [2]. Hybrid maize seed provides farmers with varieties of better genetic traits, including high yield potential and unique combinations of traits to resist disease and adverse growing conditions [3].

There are observational studies regarding the decrease in maize yields due to excessive rainfall [4], climate change marked by shifts in seasons and increasing rainfall and temperature [5], as well as significant changes in rainfall intensity in Java Island [6]. The premise to conduct this research was the concerns in maize hybrid seed production having less pollen available than commercial maize cultivation, the sensitivity of maize to water stress during the flowering period, and changes in seasonal rainfall patterns and intensity on Java Island.

1.1. Maize Hybrid Seed Production

The hybrid maize parent cultivation technique which aims to produce hybrid maize seeds is different from commercial maize cultivation of hybrid and composite/open pollination varieties. In producing hybrid seeds, two homozygous/inbred lines are crossed and the first generation (F1) is heterozygous, then planted as a hybrid variety [7]. The two inbred maize lines act as male or female parents, respectively. The highest yield potential of hybrid maize is found in the F1 generation seeds, the second generation (F2) seeds no longer give as high yields as the first generation [8].

In maize hybrid seed production, the harvest only comes from the female parent. Male parent cobs are the result of pollination with their own lines (selfing), not crosses, so they remain inbred. To prevent selfing on the female parent, the tassel on the female parent plant is removed when it just comes out of the leaf axils and before the pollen spreads [9]. This process is commonly referred to as detasseling.

To maximize yields, hybrid maize parent cultivation uses a male and female parent row pattern and is commonly referred to as the planting ratio. For example, the planting ratio is 2:1, which means that two rows of female parents are planted for every single row of male parents. The female-to-male row ratio that is often used in hybrid maize seed production ranges from 2:1 to 6:1, depending on the ability of the male parent to produce pollen [10]. In single-cross hybrid seed production, vigor and pollen production are usually very low and are best planted in a 2:1 or 4:2 ratio. Meanwhile, if the type of seed produced is a double cross hybrid and the male parent is a single cross, the ratio used is 6:2 [8].

1.2. Water Stress on Maize

The two most important environmental stressors affecting maize production are poor soil and water shortages. Acidic soil can inhibit the root growth of maize plants, resulting in insufficient nutrient absorption. The yield of maize varieties with high yield potential can be further reduced due to a lack of water during growth resulting in poorly developed root systems [11]. Excessive rainfall will interfere with plant growth and affect plant productivity [5]. The main cause of stress due to flooding and inundation is the lack of oxygen needed to carry out root system functions [2]. Stagnant water slows the growth process of maize and reduces the volume of the cob so that the ability to accumulate dry matter is reduced. Due to a lack of adequate supply of nutrients, seed formation is limited and results in impaired plant growth and development. Stress due to overcast and rain at the stage of cob hair formation causes poor pollination and low kernel count in summer maize [12]. Maize plants were most susceptible to damage when waterlogging occurred at the three-leaf growth stage (V3), six-leaf stage (V6), and 10 days after male flower tassel formation (10VT). Crop damage increases with the increasing duration of waterlogging [13].

Under drought stress, the limited water supply during the growing season causes water deficits in the soil and crops and reduces maize yields. The water requirement of maize is low in the early growth stage and then reaches its peak in the reproductive growth stage, then the water requirement decreases again during the late growth stage [14]. The peak period of water use occurs during the formation of male flower panicles and the stage of seed formation [15]. During the reproductive growth stage, 8-9 mm of water per day is required for one plant. The four most crucial weeks related to water requirements include two weeks before and two weeks after pollination [14]. The phases that are most sensitive to drought stress are the early growth and flowering phases. Drought in the early growth phase can interfere with plant growth. Meanwhile, if drought occurs in the flowering phase, female flowers appear later than male flowers, reducing the chances of successful pollination and thus disrupting the seed formation stage [16]. The stage leading to the milking stage of maize cob seeds is a period that is sensitive to water stress and has a major impact on grain yields [17].

1.3. Evapotranspiration

Evapotranspiration is a change of state from liquid H_2O into steam or gas and moves from the evaporation area (soil and vegetation surface) to the atmosphere [18]. Around 70-80% of maize water use comes from plant transpiration [2]. The use of crop water (transpiration) during the growing season is a major factor in achieving high yield potential. Groundwater loss (evaporation) and crop water loss (transpiration) occur simultaneously, making the prediction of evapotranspiration complicated. From sowing to stage V6, evaporation accounted for 70 percent of evapotranspiration while from V6 to R6 transpiration of maize crops accounted for 70 percent of evapotranspiration. Higher maize yields require more transpiration of water so the rate of evapotranspiration is higher. Usually, 9.42 tons ha^{-1} of maize uses 406.4 mm of water, 12.55 tons ha^{-1} of maize uses 508 mm of water, and 15.69 tons ha^{-1} of maize uses 558.8 mm of water. For every mm of evapotranspiration, maize yield increases by about 17 kg [19].

Reference evapotranspiration (ETo) is defined as the evapotranspiration rate of a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1}, and an albedo of 0.23. The reference surface closely resembles an extensive surface of green grass of uniform height, actively growing, completely shading the ground, and with adequate water [20].

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

ETo : reference evapotranspiration (mm day^{-1})
R_n : net radiation at the crop surface (MJ m^{-2} day^{-1})

G : soil heat flux density (MJ m^{-2} day^{-1})
T : mean daily air temperature at 2 m height (°C)
u_2 : wind speed at 2 m height (m s^{-1})
e_s : saturation vapor pressure (kPa)
e_a : actual vapor pressure (kPa)
Δ : slope vapor pressure curve air (kPa $°C^{-1}$)
γ : psychrometric constant (kPa $°C^{-1}$)

FAO-56 Penman-Monteith equation (1) is the most common equation used to estimate ETo. This equation determines the evapotranspiration from a hypothetical grass reference surface and provides standards for evapotranspiration in different periods of the year or in other regions that can be compared and evapotranspiration from other crops can be related [20]. The ETo concept was introduced to study the demand for atmospheric evaporation regardless of plant type, crop development, and management practices [21].

1.4. Soil pF Curve

The characteristic curve of soil water content or the pF curve is a curve that can describe the condition of soil water content in various matrix suctions [22]. The ability to bind water or available water is one part of the pF curve. The pF curve is the pressures applied to the soil and represents certain conditions in the field. The applied pressure usually consists of 0.01 atm (pF 1.0), 0.1 atm (pF 2.0), 0.33 atm (pF 2.54), and 15 atm (pF 4.2) [23]. Classification of soil water content includes available water, non-available water, hygroscopic water and adhesion water. Available water is in the range of field capacity and permanent wilting point (pF 2.54-4.17), water not available is water that is at a pressure above the permanent wilting point (pF > 4.17), hygroscopic water is water strongly bound by soil particles that they cannot be used by plants, water adhesion is also water that is tightly bound between soil and water so that it cannot be used by water and plants [24].

To find out the relationship between soil, water and plants, the concept of water available to plants is known, where the water available to plants is the range of values of water content in the soil according to plant needs. This condition is closely related to the soil's ability to hold water (groundwater retention), where the basic principle of available water for plants is related to the provision of sufficient and balanced amounts of water for plant growth, which is the soil water content between field capacity (pF 2.54) and permanent wilting point (pF 4.2) [25]. In many cases, the water holding capacity of the soil is considered to be equivalent to the field capacity water content. In general, the field capacity water content is defined as the soil water content in the field when the drainage water has stopped or has almost stopped flowing due to the force of gravity after the soil was completely saturated [26]. Groundwater retention, especially at pF 2.54 and pF 4.2 determines the water adequacy index which in turn determines the choice of planting time for agricultural commodities [20,27]. Soil density has a very significant effect on the pF curve, permeability and resistance, both before and after planting [28].

1.5. Previous Studies

Research on the effect of rainfall on maize yields shows varying results in different areas. Rahmani and Hariyono [29] and Herlina and Prasetyorini [5] research conducted in Wajak, Donomulyo, Dau, and Kasembon areas, Malang Regency, did not find any effect of rainfall or rainy days on maize productivity. According to Maitah *et al.* [30], rainfall showed a moderate to high positive correlation with maize grain yields in the Czech Republic. Research by Huang *et al.* [31] showed that lack of moisture determined maize yields over excess humidity based on the relationship between maize yield and rainfall in the northeastern United States, but the relationship between rainfall and maize yields in critical months was stronger in the northeast than in the southeast. The research of Bergamaschi *et al.* [32] in Southern Brazil concluded that annual maize yield variability was closely related to the amount of rainfall and that the relationship between maize yield and rainfall was closer in the reproductive period than throughout the crop cycle.

The grass reference evapotranspiration (ETo) FAO-56 PM expresses the evaporation power of the atmosphere at a certain location and time and does not consider plant characteristics and soil factors [20]. ETo FAO-56 PM does not depend on groundwater availability (because it is calculated based on the assumption of well-irrigated soil), plant species, plant development, and management practices [33]. ETo FAO-56 PM values measured or calculated at different locations or different seasons can be compared because they refer to the ET from the same reference surface [20]. Since FAO-56 PM ETo is calculated from rainfall, temperature, relative humidity, wind speed, and sunshine hours, any change in these variables is likely to change the ETo value [34].

Ramarohetra and Sultan's [33] research on the effect of FAO-56 PM ETo on millet yield simulation in Senegal found a pattern that the higher the ETo the lower the yield and it was modulated by the amount of rainfall, but in some cases, this did not happen. Research in the North China Plain used the humidity index which is the ratio between rainfall and ETo FAO-56 PM to determine its effect on maize and winter wheat yields, with the conclusion that the higher the humidity index, the higher the yield [34]. From the study, it can be interpreted that at similar rainfall, yields are higher at lower ETo FAO-56 PM. Due to the high spatial and temporal variability of rainfall as well as the complex interactions between soil-plant-water processes, regional to global scale analyzes of crop yields and rainfall may not yield significant relationships, thus small-scale analyzes may be justified to evaluate the relationship between yield, temperature, and rainfall [35].

2. Objectives

The research objectives are:

(1) To identify the relationship between rainfall and maize hybrid seed yield
(2) To identify the relationship between ETo FAO-56 PM and maize hybrid seed yield

3. Methods

This research was conducted in January-May 2022. This is an ex-post facto study; it aims to examine events that have occurred and trace back to find out the factors that can cause these events to occur with a quantitative approach.

3.1. Data Acquisition

Secondary data on maize hybrid seed yields were taken from two locations, namely Talangsuko Village in Turen District, Malang Regency, East Java with coordinates 8°08'52.5"S 112°40'34.3"E and Sukoreno Village in Umbulsari District, Jember Regency, East Java with coordinates 8°14'09.6"S 113°22'58.6"E. Planting date, harvest area, and maize yield for one pair of inbred maize parental lines in both areas were recorded between January 2017 to June 2020. Daily rainfall and ETo FAO-56 PM data on the aforementioned area from 1979-2021 were obtained from Meteoblue in the form of ECMWF Reanalysis v5 (ERA-5).

Soil from each location was used as supporting primary data. Intact soil core samples were collected from two spots in each location. The samples were analyzed in Soil Physics Laboratory at the Faculty of Agriculture, Universitas Brawijaya, Malang. The soil samples were analyzed for their pF curve and soil texture. A literature comparison was carried out to find out the comparison of soil analysis results obtained with soils in other studies with the same texture class.

3.2. Data Analysis

The consistency of a rainfall record is tested with double-mass analysis before being analyzed. A series of rainfall data at one particular station cannot be directly used for analysis because the data in it may come from different data populations, therefore a consistency test is required. The consistency test is represented by a double mass curve, which is a graph of the relationship between the cumulative rainfall of the test station and the cumulative average rainfall of the test station. Consistent data will form a straight-sloping line with a certain slope value while inconsistent data will form a line that changes its slope at a certain point. The results of this test will show whether the rainfall data recorded at a test station is consistent with the development of data from test stations [36].

Data analyses consisted of 4 categories:

(1) Effect of total rainfall during the growing season on maize yields
(2) Effect of total ETo during the growing season on maize yields
(3) Effect of rainfall in the flowering period on maize yields
(4) Effect of the number of rainy days that reached the maximum amount of water available to plants at a soil depth of 20 cm on maize yields

Data were analyzed with a 95% confidence level using t-test and regression analysis in Microsoft Excel 2019 and Minitab 19. One growing season consists of 110 days. The flowering period occurs for 2 weeks and is specified at 63-77 days after planting.

Calculation of the maximum amount of water supply in the soil available to plants uses the following formula [37]:

$$FC - WP \times RD \quad (2)$$

FC: field capacity (%)
WP : wilting point (%)
RD : rooting depth (mm)

The rooting depth used is 20 cm. Maize root weight in the top 20 cm of soil contributes 63-85% of root weight in soil profiles 0-60 cm under different irrigation regimes [38]. If the rainfall for 3 days during the growing season reaches the maximum value of water supply, then it is counted as 1 effective day. Field capacity indicates the amount of water retained in the soil after excess water is drained and the rate of downward movement decreases, which usually occurs 2-3 days (48-72 hours) after precipitation or rain [39].

4. Results and Discussion

From the results of the analysis of soil samples taken at both locations, it was found that the soil in Talangsuko had a sandy clay loam texture class while the soil in Sukoreno had a clay texture. the pF curve is illustrated in Fig. 1. The average water content in the pF 2.5 of Talangsuko soil was 41%, lower than that of Sukoreno soil with an average of 50.5%. In Talangsuko soil, the average moisture content at pF 0 was 57.5% of the total weight of the soil, while in Sukoreno soil it was 62.5%. The water content at pF 0 is the amount of pore space contained in the soil [22]. The water content in clay texture is greater than that of sandy clay loam and sandy loam textures because the water-holding capacity of clay-textured soil is greater than that of sandy clay loam and sandy loam-textured soils [40]. The average bulk density of Talangsuko soil is 1.39 g cm^{-3}, while that of Sukoreno soil is 1.32 g cm^{-3}. Clay textured soils have a high total pore space so they have a lower bulk density.

On the other hand, sandy soils have a smaller total pore space, so the bulk weight becomes larger [41].

Consistency test was conducted on Talangsuko and Sukoreno daily rainfall data from 2017-2020. Each location's rainfall data was compared to the mean of 4 other weather stations' rainfall data in the surrounding area near Malang and Jember. Breaks in the double-mass curve are caused by changes related to the variables. These changes may be due to alterations in the method of data collection or physical changes that affect the variables [42]. Based on Fig. 2, both data are consistent since there are no apparent breaks or changes in slope.

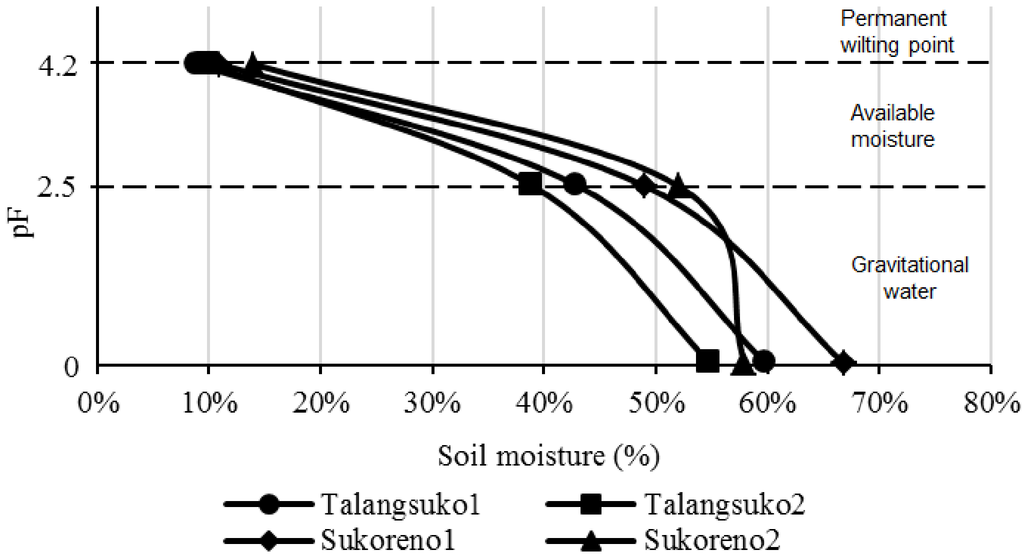

Figure 1. pF Curve of Talangsuko and Sukoreno Soil Sample

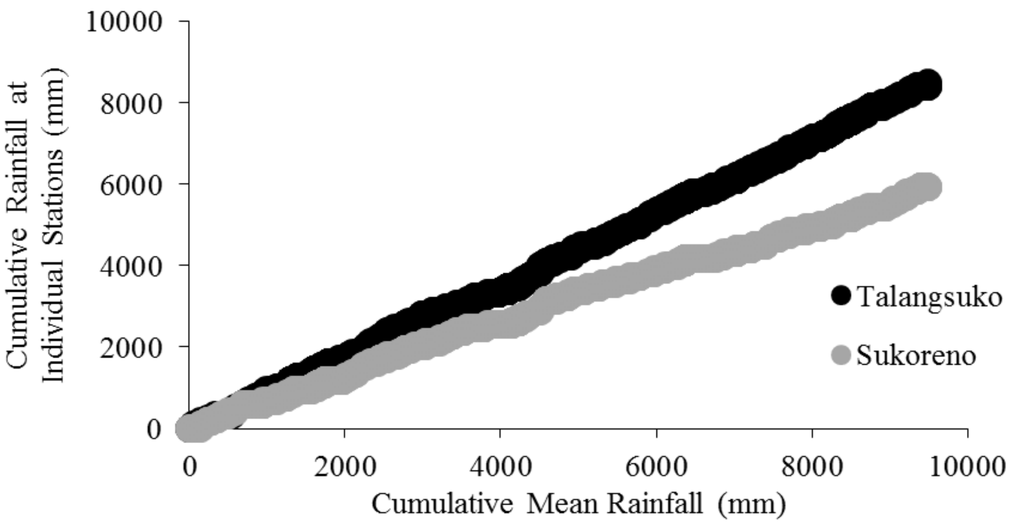

Figure 2. Rainfall Consistency Test on the Year 2017-2020

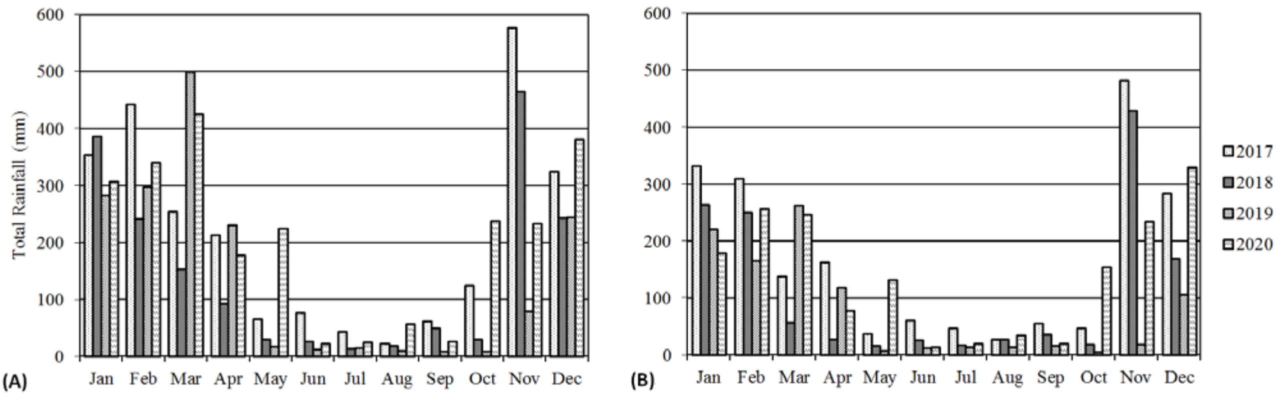

Figure 3. Monthly Rainfall in Talangsuko (A) and Sukoreno (B)

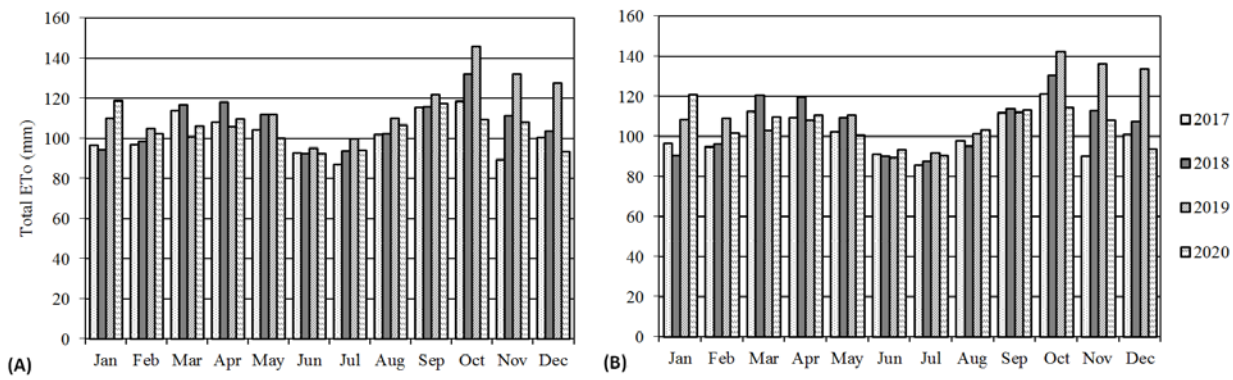

Figure 4. Monthly ETo in Talangsuko (A) and Sukoreno (B)

Fig. 3 shows that on average, Talangsuko received a higher rainfall rate than Sukoreno. The average yearly rainfall in Talangsuko was 2188 mm, while in Sukoreno the average was 1491 mm. However, ETo in both locations was very similar. The average yearly ETo in Talangsuko was 1285 mm while in Sukoreno it was 1272 mm, there was only a 13 mm ETo difference yearly between both locations.

Rainfall in both locations peaked in November with an average of 338 mm in Talangsuko and 290 mm in Sukoreno, except in 2019 when Indonesia experienced an extended dry season. Peak dry season was generally in July, both locations had an average of 24 mm of rainfall in that month. In those four years, 2017 was the wettest year with 2559 mm of total rainfall in Talangsuko and 1978 mm in Sukoreno. The driest year was 2019 with Talangsuko experiencing 1707 mm of total rainfall and 959 mm in Sukoreno.

In Fig. 4, ETo was highest in October in both locations with an average of 126 mm in either location. In Talangsuko, the lowest ETo occurred in June with an average of 93 mm and in Sukoreno it was in July at 88 mm. ETo fluctuation varies depending on the location e.g., in Sumbawa, West Nusa Tenggara, the highest ETo values were observed in September and the lowest in February [43].

The statistical model to predict ETo may not be linear but a polynomial model [44]. Liu et al [45] reported precipitation has a negative correlation with reference evapotranspiration in the hilly regions in southern China on an annual and seasonal basis. Irmak et al [46] also found annual ETo FAO-56 PM significantly inversely correlated with rainfall and relative humidity (RH) in Central Nebraska, USA. On the other hand, Zhang and Wang [47] found potential evapotranspiration (ETp) to be positively correlated with rainfall in Hancang River Basin, China. The correlation between ETp and precipitation is the third highest after solar radiation and average temperature. In Indonesia, ETp correlates weakly with precipitation, but strongly with elevation, confirming air temperature as the primary controlling variable [48].

Data from the wet season were fewer than in the dry season mainly because the preferred time to begin maize cultivation for the local farmers was at the end of the monsoon or during the dry season. The total harvest area in Talangsuko was the highest from the May planting month with an average of 16.68 ha. In Sukoreno the peak planting month was relatively similar in March, April, and July with the average around 2-3 ha. The most productive year in both locations was 2017 with the total harvest area in Talangsuko reaching 68.53 ha and 30.74 ha in Sukoreno.

Average maize hybrid seed yields are presented in Tables 1, 2, and Fig. 5. Overall, the average maize yield in Talangsuko was higher than in Sukoreno. The average yield in Talangsuko was 8 ton ha^{-1} and in Sukoreno it was 5 ton ha^{-1}. The highest average yield in Talangsuko is in June at 8.94 ton ha^{-1} and at the lowest in October at 2.39 ton ha^{-1}. Sukoreno has the highest average yield in August at 6.53 ton ha^{-1} and the lowest in February at 4.54 ton ha^{-1}.

Table 1. Average Maize Hybrid Seed Yield in Talangsuko

Planting Month	Average Maize Yield (ton ha^{-1})				Average
	2017	2018	2019	2020	
Jan	3.84	-	-	-	3.84
Feb	4.30	6.15	5.55	-	5.33
Mar	-	6.57	8.86	-	7.72
Apr	8.48	9.61	8.43	7.24	8.44
May	9.11	7.81	9.21	8.28	8.60
Jun	9.30	8.81	9.56	8.08	8.94
Jul	7.22	9.76	6.16	-	7.71
Aug	5.71	-	-	-	5.71
Sep	2.81	-	-	-	2.81
Oct	3.36	1.41	-	-	2.39
Average	6.01	7.16	7.96	7.87	

Table 2. Average Maize Hybrid Seed Yield in Sukoreno

Planting Month	Average Maize Yield (ton ha^{-1})				Average
	2017	2018	2019	2020	
Feb	-	4.54	-	-	4.54
Mar	3.69	6.87	4.46	5.36	5.10
Apr	4.43	6.62	5.02	6.16	5.56
May	3.80	7.40	-	4.29	5.16
Jun	5.79	5.75	-	-	5.77
Jul	4.39	6.25	6.90	-	5.85
Aug	-	7.38	5.67	-	6.53
Average	4.42	6.40	5.51	5.27	

In Fig. 6, the regression model shows that rainfall has a strong relationship with maize yields in Talangsuko and Sukoreno with a coefficient of determination (R^2) of 0.60 and 0.61. In Talangsuko, the relationship between rainfall and maize yields is negative and linear, an increase of 1 mm in rainfall can reduce yields by 4.5 kg. In Sukoreno, the relationship between rainfall and maize yields is quadratic, increasing rainfall decreases maize yields until rainfall reaches 661.11 mm, then yields increase as rainfall increases.

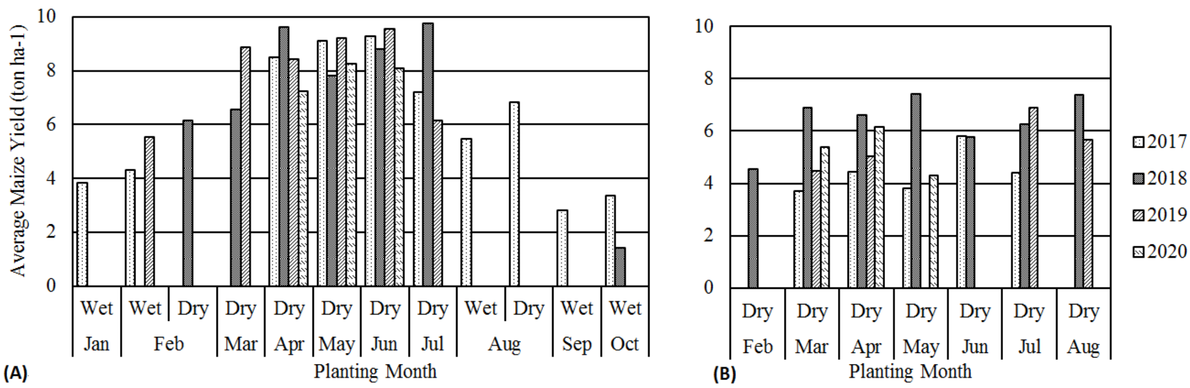

Figure 5. Average maize hybrid seed yield in Talangsuko (A) and Sukoreno (B)

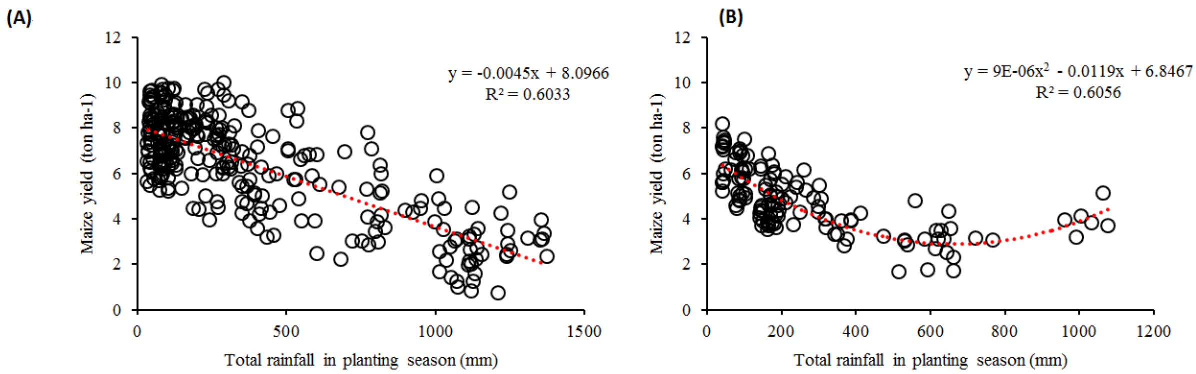

Figure 6. Regression model of rainfall and maize yields in (A) Talangsuko and (B) Sukoreno

Previous studies have shown mixed results, research in other districts in Malang found no effect of rainfall or rainy days on maize productivity [5,29]. Positive correlations between rainfall and maize yields were found in the Czech Republic [30], Gboko [49], Lagos in Nigeria [50], Hungary [51], and Ghana [52]. Rainfall from December to April is negatively correlated with maize yields in Mbeya, Tanzania [53].

The studies mentioned above show that rainfall and maize have a positive correlation in rainfed land in drier areas. In the lowland tropics, 400-500 mm is the lower limit for optimal maize cultivation, in the tropics it is 350-450 mm, and in the highlands 300-400 mm. During the reproductive growth phase, it takes 8-9 mm of water per day for one plant [14]. Talangsuko and Sukoreno are in a tropical monsoon (Am) climate with altitudes of 420 m and 23 m above sea level, respectively. The land used for maize cultivation as a data source for this research has access to irrigation. This could explain why the relationship between rainfall and crop yields is negative even though rainfall in both locations during the dry season was much lower than recommended.

In Fig. 7, the regression model shows that ETo is not related to maize yields in Talangsuko and Sukoreno, with a coefficient of determination of 0.05 and 0.06. Because irrigation is available in maize cultivation fields, conditions of excess water are more likely to be experienced by fields than water shortages. The excess water availability can weaken the impact of evapotranspiration that occurs on the land.

In Fig. 8, the regression model shows that rainfall during the flowering period (63-77 days after planting) has a strong relationship with maize yields in Talangsuko with a coefficient of determination of 0.60, but there is no relationship in Sukoreno shown by a coefficient of determination of 0.09. In Talangsuko the relationship is in the form of a quadratic curve, an increase in rainfall during the flowering period reduces maize yields until the rainfall reaches 337.21 mm, then the graph slopes down.

Based on the description of the characteristics of the lines, the male inbred lines used in this study achieved 50% pollen release at 63 days after planting (DAP), and the female lines achieved 50% silking at 64 DAP. From this reference, the rainfall during the flowering period can be known. Pollen shedding occurs over several days (usually 5 to 10), with peak production around the third day [54]. Differences in the age of flowering between male and female parents have an effect on maize seed yield [55], under ideal conditions pollen in the male parent and cob hair in the female parent appear simultaneously. Therefore, factors that cause delayed and premature flowering in either parent can lower the flowering synchronization rate. In the case of Talangsuko, what could have happened is that the pollination process was not optimal due to rain, or excess water in the land which causes the plants to experience inundation stress, resulting in a decrease in crop yields. The findings of Huang *et al.* [56] showed that standing water on V6-VT waxy corn had the most severe effect, followed by VT-R1 and R1-R3. Stress due to overcast and rain during cob hair formation causes poor pollination and low kernel count in summer maize [12]. Whereas in the case of Sukoreno only a few samples experienced rain during the flowering period, so the relationship with crop yields could not be determined. Variations in maize yields can be attributed to other factors such as soil characteristics, farming methods, sowing dates, weeds, fertilizer applications, seed varieties, pests and diseases, yields and rainfall characteristics/other climatic factors [49].

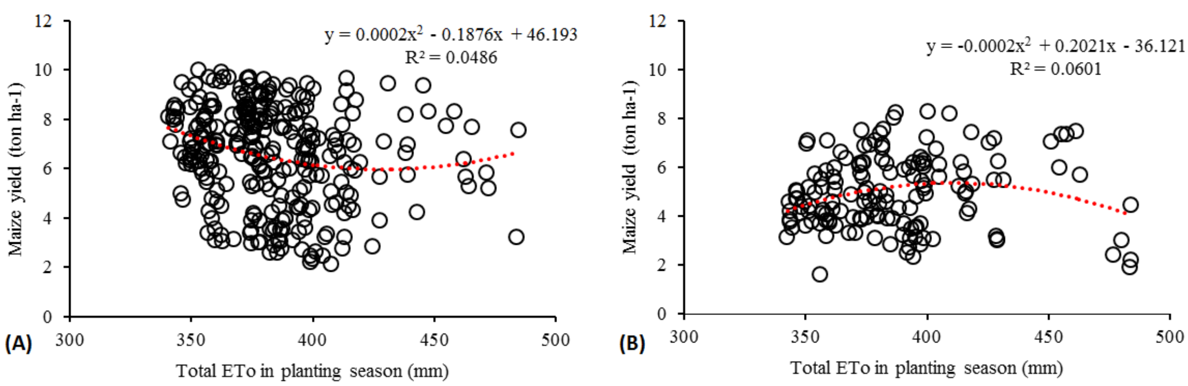

Figure 7. Regression model of ETo and maize yields in (A) Talangsuko and (B) Sukoreno

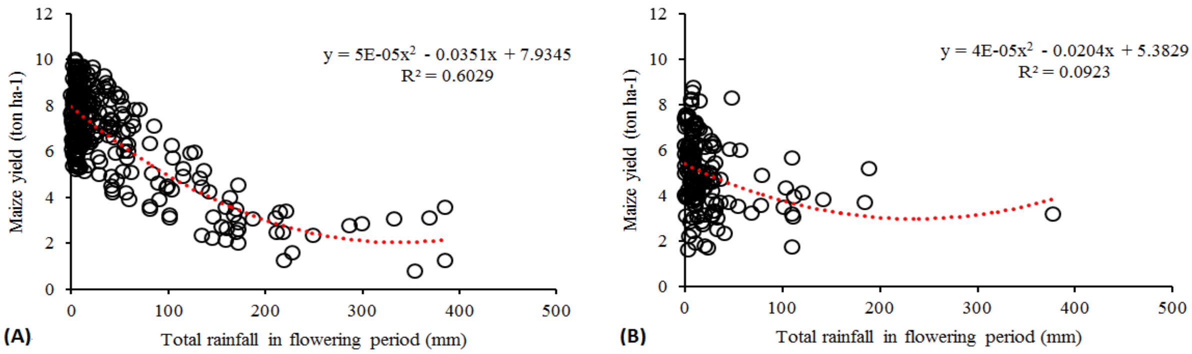

Figure 8. Regression model of rainfall in flowering period and maize yields in (A) Talangsuko and (B) Sukoreno

Walidayni's [57] research in Malang Regency found that soil with a sandy clay loam texture has a water content value of 25.86% at pF 2.54 and 16.94% at 4.2 pF. Whereas in soils with a clay texture the water content at pF 2.54 is 29.39% and at pF 4.2 it is 21.35. Sandy clay loam soil water content decreased from 54.46% to 38.32% on the 5th day after irrigation. Whereas in clay the water content decreased from 51.04% to 42.34% on the 5th day after irrigation. Andriana's [58] research in Mataram found that the average daily loss of moisture in sandy clay loam under water-saturated conditions at a depth of 0-30 cm for 8 days ranged from 0.05-7.5% per day with the smallest decrease on the fourth day. Marhaban's [59] research in Bogor obtained soil permeability with a sandy clay loam texture of 35.55-64.82 cm h^{-1}, with an average value of water content at pF 2.54 of 28% and pF 4.2 of 15.55%. Mustawa *et al.* [60] study in East Lombok obtained soil porosity with a clay texture of 54.45% and 40% sandy clay loam. Clay texture has the highest level of storage efficiency and irrigation use compared to loam and sandy clay loam textures. Maqdisa *et al.* [61] research in Asahan District found soil with a sandy clay loam texture containing 1.68% organic matter, 50.52% water content, 1.01 g cm^{-3} bulk density, 2.04 g cm^{-3} particle density, and a porosity of 50% with an infiltration capacity of 37 x 10^{-6} m s^{-1} (fast). Adesigbin and Fasinmirin's [62] study in Nigeria found soil with a tilled sandy clay loam texture had an average bulk density of 1.52 g cm^{-3}, an average total porosity of 42.5%, a cumulative infiltration rate at 2 cm s^{-1} suctions of 3.46 cm s^{-1}, and hydraulic conductivity of 9.09 x 10^{-3} cm s^{-1}.

When compared with studies in the previous paragraph, it was found that the average porosity or water content in the pF 0 sandy clay loam soil in Talangsuko, which was 58%, was higher than the sandy clay loam soil in the aforementioned studies. The same thing was also found in the average water content at field capacity or pF 2.5, which was 41%. Permanent wilting point or moisture content at pF 4.2 in Talangsuko was lower than in other studies. While the average bulk density is 1.39 g cm^{-3}, lower than the soil in Adesigbin and Fasinmirin's [62] study which reached 1.52 g cm^{-3}. The same thing was also found in the comparison of Sukoreno clay soil with other studies, with average porosity and field capacity higher than other studies with values of 62.5% and 50.5%, as well as a lower permanent wilting point with a value of 12.5%.

Higher soil porosity and field capacity can benefit plant growth because they can store more water and have a greater water supply. Meanwhile, a low permanent wilting point can increase the availability of water when the soil is dry. The high quality of the soil in Talangsuko and Sukoreno could be caused by the application of materials that can improve soil quality such as biochar or organic fertilizers. The application of biochar can significantly increase the available soil pores and reduce bulk density in sandy clay loam soils [63]. Available water content (pF 4.2-2.54) significantly correlated positively with organic matter, total pore space and micropores. The higher the organic matter content, total pore space, and micro pores of the soil, the higher the available water content of the soil [64]. Intara *et al.* [65] research concluded that the application of organic matter in the form of chicken manure and compost can reduce the rate of evaporation that occurs in the soil. Soils with a clay texture have a lower evaporation rate when compared to clay loam soils. Applying organic matter to soils with a clay texture can increase soil water content and available water capacity and reduce soil unit weight. The soil bulk density value in Adesigbin and Fasinmirin's [62] study is high because the land had just been tilled, whereas in the Talangsuko soil sample the land was not used for cultivation at the moment. The bulk density of the soil has a significant effect on the water content of the field capacity. Soil texture and organic matter content significantly affect the moisture content of the permanent wilting point [57].

The higher the percentage of sand in the soil texture, the easier it is for water to pass into the soil. However, the ability of soil to transmit water does not only depend on soil texture. Many other factors can influence it, such as porosity, organic matter, and continuity of soil pores [66]. Clay-textured soils have a higher available water capacity than clay-textured soils because clay-textured soils generally have more micro pores so the amount of water that can be held is greater, which means that the available water capacity is also higher [65]. This statement is reflected in the results of soil analysis where the sandy clay loam in Talangsuko with an average clay percentage of 28% has a moisture content of 41% at field capacity (pF 2.5), while the clay soil in Sukoreno with an average clay percentage of 51.5% has a moisture content of 50.5% at field capacity.

The water content in clay texture is greater than that of sandy loam and sandy clay loam textures, because the water holding capacity of clay textured soil is greater than that of sandy loam and sandy clay loam-textured soils [40]. Clay not only has a large surface area but is also negatively charged. The negative charge causes clay to have a higher ability to hold water, the number of micro pore spaces in the clay is much larger than the number of micro pore spaces between the sand grains so that the movement of water and air in the clay fraction is inhibited [65]. Therefore, it could be inferred that clay in Sukoreno has a lower infiltration capacity compared to sandy clay loam soil in Talangsuko. Arianto *et al.* [67] found that gleisol soil with a clay texture and flat slope in the Cikeruh Sub-watershed has a constant infiltration rate of 1.12 cm h^{-1} (rather slow).

In the sandy clay loam soil in Talangsuko, the average maximum amount of water available for plants at a soil depth of 20 cm was 63 mm, while in the clay soil in Sukoreno it was 76 mm. Because only a few samples in Sukoreno experienced more than 76 mm of consecutive rainfall, the comparison used a value of 63 mm. In Fig. 9, the regression model shows that the number of rainy days that reach the maximum amount of water available for plants at a soil depth of 20 cm has a strong relationship with maize yields in Talangsuko with a coefficient of determination of 0.63, but there is no relationship in Sukoreno marked with a coefficient of determination of 0.18. In Talangsuko, the relationship is in the form of a quadratic curve, an increase in the number of rainy days that reaches the maximum amount of water available at a soil depth of 20 cm reduces maize yields until the number of rainy days reaches 18.35 days, then the graph flattens out.

The model above is similar to the relationship between rainfall in the flowering period and maize yields, in Talangsuko the relationship tends to be negative and in Sukoreno there are not many samples that experienced consecutive rains up to 63 mm. The regression relationship in Sukoreno remains unobservable when using a value of 76 mm as the average maximum amount of water available for plants at a soil depth of 20 cm, with a coefficient of determination of 0.17. Judging from the results of soil analysis, clay in Sukoreno has a higher porosity with a value of 62.5% compared to sandy clay loam soil in Talangsuko with a value of 57.5%, so it has a greater ability to store water and requires a larger volume of water to saturate. The water content at field capacity is also higher with a value of 50.5% compared to Talangsuko soil with a value of 41%, so there is less water that cannot be absorbed by plant roots due to gravity and experiences percolation in the lower layers of soil

The results of the regression test showed a negative relationship between total rainfall during the growing season and maize yields in both Talangsuko and Sukoreno (Fig. 6). And seeing the strong relationship between the number of rainy days which reaches the maximum amount of water available for plants at a soil depth of 20 cm in Talangsuko (Fig. 9), conditions that could have occurred were inundation stress which inhibited the growth of maize plants and reduced crop yields. If the yields in Talangsuko with a sandy clay loam texture could be affected by inundation stress, then it can be assumed that the yields in Sukoreno with a clay texture were also affected by inundation stress. Soil properties that can be a limiting factor for the growth of maize in Sukoreno are the water infiltration capacity of clay soil which is lower than that of sandy clay loam soil. Despite having a higher porosity, the slow infiltration capacity can cause the soil to be inundated for a longer duration. The fineness of the clay grains causes the arrangement of the soil grains to be very tight, so that it is difficult for water and air to enter them. As a result, the soil is difficult to absorb water and the water that has entered will be difficult to get out, therefore the clay dries slowly [68].

The effect of inundation stress on maize plants depends on the time of stress occurrence. With the extension of the waterlogging duration at the germination stage of maize seeds, seed respiration changes from aerobic to anaerobic respiration. This phenomenon can cause the growth of seedlings with defects [69]. Tolerance to flooding generally increases with the increasing age of the plant, but oxygen deficiency which inhibits root function before and during pollination may have a greater effect on reduced yields compared to if it happens during vegetative growth or seed filling [2]. Water stress before V4 to V5 growth stages may cause slight yield loss if the plant survives, but tassel and cob development starts at V6, therefore water stress can cause more damage in this period than in the nursery stage, and the damage will be more severe when the stress is close to the time of tassel emergence [70]. The four most important weeks regarding water requirements include the two weeks before and after pollination [14]. At stage V12, the potential number of rows of seeds and ovules is established. Plant stress around V12 can cause corn cobs to have a normal number of rows of seeds around the cob but shorter cobs than normal [54]. The number of cobs and seeds per cob was determined after fertilization. However, moisture stress, especially with high temperatures, nutrient deficiencies, disease, or insect attack, will reduce seed size and weight, and will determine whether the seeds at the cob end will fill even if pollinated [54]. In the dough phase (R4), starch accumulation continues in the endosperm. Kernel dry matter content at the beginning of the dent phase (R5) is only about 45% of the final yield, stress can continue to limit the accumulation of seed dry weight between the dent stages and physiological maturity [71]. Too much rainfall can reduce maize yields through direct physical damage, delayed planting and harvesting, and depletion of oxygen and loss of nutrients from the soil [4].

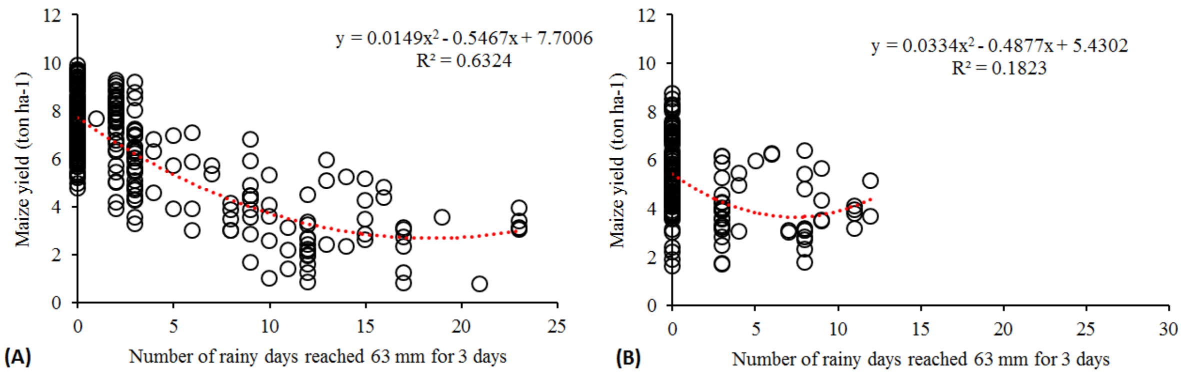

Figure 9. Regression model of the number of rainy days reached 63 mm for 3 days and maize yields in (A) Talangsuko and (B) Sukoreno

5. Conclusions

There was a strong linear and negative relationship between rainfall and the yield of hybrid maize seeds in Talangsuko Village (R^2=0.60), an increase of 1 mm of rainfall could reduce yields by 4.5 kg. In Sukoreno Village, the relationship was in the form of a quadratic curve (R^2=0.61), an increase in rainfall decreased maize yields until rainfall reached 661.11 mm, then yields increased with increasing rainfall.

In Talangsuko, a strong relationship was found between rainfall during the flowering period and maize yields (R^2=0.60), as well as between the number of rainy days that reached the maximum amount of water available to plants at a soil depth of 20 cm and maize yields (R^2=0.63). In Sukoreno, only a few samples experienced rain during the flowering period and consecutive rains, therefore the relationship with maize yields could not be concluded (R^2=0.09 and 0.18).

There was no relationship between ETo FAO-56 PM and hybrid maize seed yield (R^2=0.04 and 0.06). The excess water availability weakened the impact of evapotranspiration that occurred on the land.

Further studies are needed using predictor variables that can comprehensively explain historical data on yields of hybrid maize seeds on irrigated land.

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