Water requirement for cocoa (Theobroma cacao L.) plant and the effect of climate factors on the distribution of the cocoa pod borer attacks (Conopomorpha cramerella Snellen) in North Luwu Regency using Cropwat 8.0

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Abstract. The research aims to determine the water requirements level for cocoa plant growth, and study the effect of climate factor on the area of cocoa pod borer attack. The research was conducted from April to July 2019 in Batu Alang Village, Sappang district, North Luwu Regency, South Sulawesi. The research consisted of two stages ie. Survey (literature study, observations, and interviews) to obtain dataset for climate, soil and cocoa plant growth and desktop study (simulation using Cropwat 8.0) to run the model using dataset previously obtained from the survey. The results show that evapotranspiration of cocoa (ETc) on stage 1 is 106.53, Stage 2 is 114.2, Stage 3 is 106.2, and Stage 4 is 85.1. Based on the ETc and the effective rainfall values in the study sites, water needs of cocoa plants in North Luwu Regency for all growth stages are adequate. The highest attack area of cocoa pod borer of 8332 ha occurred in February attributed to climatic conditions with an average temperature of 27.2 °C, 81% humidity, and 308 mm rainfall. On the other hand, the lowest attack area was 3224 ha in May that can be attributed to an average air temperature of 27.4 °C, 83% humidity, and 384 mm rainfall. Some climate factors do not have significant influence on the development and the widespread of the cocoa pod borer attacks.

1. Introduction
South Sulawesi is one of the largest contributing provinces for cocoa in Indonesia, with a total area of 240,580 hectares and a total production of 112,381 tons of dry beans per year [1]. Cocoa is cultivated by farmers and spread in various districts in the South Sulawesi Province, one of which is North Luwu Regency. One of the problems in cultivating cocoa in North Luwu Regency is the plant pests attack such as the cocoa pod borer (Conopomorpha cramerella Snellen). In addition, other problems that affect the productivity of cocoa are inappropriate management of soil resources and the availability of water or rainfall in this case as a result of climate change [2].

Climate is one of the environmental components that is a determining factor for the success of a crop cultivation business. Climate is a weather condition that is periodically similar every year and lasts for a long time [3]. The interaction between climate and plant genetic factors will affect plant growth and quality[4]. Therefore, climate plays an important role in short-term and long-term planning in the management of crop cultivation [5].
Climate changes is generally indicated by the changes in average daily temperature, rainfall patterns, sea level, and climate variability, for example El Nino and La Nina. The increase in temperature gives the tendency for arid regions to become drier and humid regions will get wetter, so that the preservation of water resources is disturbed. This change has a serious impact on various sectors in Indonesia, including the health sector, agriculture, economy and others [6].

Cacao plants are categorized as drought sensitive plants. Water deficit conditions will have a more negative effect on the production component such as seed yield than the growth component of the cocoa [7]. Solar radiation and high temperatures and differences in humidity (vapor pressure) in the air and leaves during periods of drought / water deficit, have a negative impact on CO2 assimilation in the cocoa metabolism process. As a result, cocoa growth and production declined [8]. Despite this, cocoa productivity can be increased in several ways, one of which is by determining the amount of water needed for cocoa plants, so that water deficit or surplus events can be prevented /overcome. Determination of plant water needs is important to do, because plant water needs are a major limiting factor for crop productivity. In cocoa plants, water shortages need to be met by irrigation, while surplus water can cause various pests and plant diseases, even rainfall that exceeds 4,500 mm / year can cause fruit rot [9].

Climate factors such as temperature, humidity, day length can affect the development of pests and diseases both directly and indirectly. These climate parameters affect the life cycle, length of life, and ability of diapause insects. The results of the study by Sharkawi et al. [10] showed that at lower temperatures the population and percentage of cocoa pod borer attacks were higher than at lower temperatures. The role of environmental factors is now increasingly important, especially in relation to climate change which has caused changes in weather patterns and temperatures in various places. Cocoa cultivation area, is one of the most likely affected by these conditions.

2. Methodology
The research was conducted from April to July 2019 in Batu Alang Village, Sabbang District, North Luwu Regency, South Sulawesi Province. The location is at an altitude of 25-100 m above sea level and have a tropical climate with temperatures of 26 °C - 29 °C, average monthly rainfall ranged from 100 to 400 mm with the number of rainy days of 212 days per year.

The study consisted of two stages namely survey and desktop study. The survey was aimed to collect climate data for the past five years, geographical data of North Luwu Regency, and data on cocoa pod borer infestation in the field. On the other hand, the desktop study was aimed to conduct data processing and simulation with Cropwat 8.0. The climate data processing was carried out in the Laboratory of Agro-climatology and Biostatistics at the Faculty of Agriculture, Hasanuddin University.

2.1. Data types and sources
Two forms of data used in this study were primary data and secondary data. The primary data were obtained from interviews on the cocoa stakeholders including cocoa experts and farmers, direct observations in the field, and soil analysis. Secondary data included geographical and climate data, pest attack area data on the study site and other supporting data obtained from related agencies and from various other publications. Climate data for 2014-2018 of North Luwu Regency obtained from Class 1 Climatology Station Maros (ogimet.com website and tutiempo.com). While extensive data on cocoa pod borer infestation in 2014-2018 were obtained from the UPTD Plantation Plant Protection Agency (BPPT).

2.2. Data analysis
Determination of crop water requirement was done using Cropwat 8.0 software. The output of the model is the amount of crop evapotranspiration (ETc), the value of which is equivalent to the plant's water needs. Data used in determining ETc include: climate data in the form of maximum and minimum temperatures (°C), relative humidity (%), wind speed (km/day), solar radiation (MJ/m²/day),
and effective rainfall (mm), and plant data in the form of Kc value, plant development phases (day), soil depth (m), plant height (m), critical depletion, and yield response factor. The amount of solar radiation is obtained from the solar irradiation (hours) data, while the effective rainfall (mm) is obtained from rainfall data (mm).

3. Results and discussion

3.1. Study location condition

North Luwu Regency is one of the regions within the administrative area of South Sulawesi Province, which is located about 430 km to the north of Makassar, the capital of South Sulawesi Province or geographically located between 2°30'45" - 2°37'30" South latitude and 119°41'15" - 121°43'11" East longitude. The altitude varies from 0 to 1,500 m above sea level. The area of North Luwu Regency is 7,502.58 km² with a population of 321,979 people [11]. The study site, Sabbang Subdistrict, Batu Alang Village. Batu Alang Village has an area of 525.08 km² with a height that varies between 25-100 m above sea level. The total population of Batu Alang Village is 37,855. The extent of cocoa plantations in Batu Alang Village is 427.08 ha [12].

3.2. Climate data analysis

Input of climate data needed for analysis with the Cropwat model to obtain the radiation and potential evapotranspiration values are shown in table 1. Figure 1 shows the dynamics of the evapotranspiration potential and radiation. Table 1 and figure 1 indicate that the largest radiation energy and evapotranspiration potential occurred in November.

Table 1. Output of radiation and potential evapotranspiration from Cropwat 8.0 based on climate data in North Luwu Regency in 2014-2018.

| Month | T Min (°C) | T Max (°C) | Humidity (%) | Wind speed (km/day) | Day length (hour) | Rainfall (mm) | Rad (MJ/m²/day) | ETo (mm/day) |
|-------|------------|------------|--------------|---------------------|-----------------|---------------|----------------|--------------|
| Jan   | 23.7       | 33.2       | 80           | 4                   | 6.8             | 242.0         | 19.7           | 4.09         |
| Feb   | 23.7       | 32.9       | 81           | 3                   | 7.3             | 308.0         | 21.0           | 4.35         |
| Mar   | 23.8       | 32.6       | 83           | 3                   | 7.6             | 367.0         | 21.5           | 4.44         |
| Apr   | 23.8       | 32.5       | 83           | 3                   | 8.0             | 419.0         | 21.2           | 4.33         |
| May   | 24.0       | 32.2       | 83           | 3                   | 7.4             | 384.0         | 19.0           | 3.87         |
| Jun   | 23.4       | 31.1       | 84           | 3                   | 4.6             | 383.0         | 14.4           | 2.95         |
| Jul   | 23.0       | 31.1       | 82           | 3                   | 6.2             | 234.0         | 16.9           | 3.34         |
| Aug   | 22.8       | 31.3       | 80           | 3                   | 6.9             | 190.0         | 18.9           | 3.73         |
| Sep   | 22.7       | 32.4       | 76           | 4                   | 9.1             | 195.0         | 23.3           | 4.57         |
| Oct   | 23.1       | 33.3       | 76           | 4                   | 8.8             | 236.0         | 23.2           | 4.64         |
| Nov   | 24.1       | 33.6       | 79           | 3                   | 9.0             | 248.0         | 23.1           | 4.73         |
| Dec   | 24.0       | 33.3       | 80           | 3                   | 7.3             | 353.0         | 20.2           | 4.19         |
| Average | 23.5       | 32.5       | 81           | 3                   | 7.4             | 3559.0        | 20.2           | 4.10         |
Figure 1. Potential evapotranspiration and radiation output from Cropwat 8.0

The climate data input, including air temperature and humidity, wind speed and day length, resulted in model output of the radiation and potential evapotranspiration values. Potential evapotranspiration is a combination of two processes, namely evaporation and transpiration. Table 1 shows that in November the maximum temperature could reach 33.6 °C, and minimum temperature of 24.1 °C, humidity of 79%, and wind speed of 3 km/day, day length of 9.0 hours which then resulted in the highest potential evapotranspiration value compared to the other months. The higher temperature coupled with the high wind speed and high irradiation time will have an impact on the high intensity of radiation and hence, the potential evapotranspiration. In irrigation planning, the assessment of the amount of water needed for an area does not separate evaporation and transpiration. This is because the water used by plants for metabolic processes is only a little or less than 1%, so that value is ignored.

3.3. Rainfall data analysis
Rainfall data input using the Cropwat model produces an effective rainfall calculation. Table 2 shows input data of monthly rainfall data and output of the model in form of effective rainfall data. The highest rainfall intensity was in April and the lowest rainfall was in August.

Table 2. Average monthly rainfall data in five years (2014-2018) of North Luwu Regency and effective rainfall from Cropwat 8.0 output.

| Month      | Rainfall (mm) | Effective rainfall (mm) |
|------------|---------------|-------------------------|
| January    | 242.0         | 148.3                   |
| February   | 308.0         | 155.8                   |
| March      | 367.0         | 161.7                   |
| April      | 419.0         | 166.9                   |
| May        | 384.0         | 163.4                   |
| June       | 383.0         | 163.3                   |
| July       | 234.0         | 146.4                   |
| August     | 190.0         | 132.2                   |
| September  | 195.0         | 134.2                   |
| October    | 236.0         | 146.9                   |
| November   | 248.0         | 149.6                   |
| December   | 353.0         | 160.3                   |
Cropwat model 8.0 simulates the effective rainfall from the rainfall data input in five years. Effective rainfall is the amount of rainfall that is effectively used by the plants to meet their water requirements. From table 2, it is indicated that the highest rainfall intensity occurred in April which was 419 mm and the lowest rainfall occurred in August. Although the intensity of rainfall is high in April, the effective rain used by plants is only 166.9 mm from the total amount of rainfall in April. According to Susilawati [13], not all falling rainfall is used by plants, because some of the rain is lost due to runoff or due to deep percolation, far outside the root area of the plant.

3.4. Crop water requirement analysis

3.4.1. Plant and soil characteristics. In order to run the Cropwat model to obtain the plant water requirement based on the plant evapotranspiration, some input data are necessary such as plant coefficient (Kc) value and other cacao plant growth characteristics such as phenology root depth, critical depletion rate, and plant yield. These characters values were obtained from observation and literature studies [2, 14, 15] with a Kc values that have been adjusted to tropical climatic conditions. Table 3 shows the input data to run the model in calculating the water requirements for the cocoa plant in the North Luwu Regency.

| Parameters                        | Initial | Developing | Advanced | End | Total |
|-----------------------------------|---------|------------|----------|-----|-------|
| Kc values                         | 0.90    | -          | 0.96     | 0.95| -     |
| Phase duration (days)             | 60      | 90         | 120      | 90  | 360   |
| Root depth                        | 200     | -          | -        | 200 | -     |
| Critical depletion (fraction) [16]| 0.30    | -          | 0.30     | 0.30| -     |
| Yield responses (coefficient) [2] | 0.20    | 0.50 [2]   | 0.70 [2] | 0.20| 0.70  |

Kc values for each plant recommended by FAO were obtained from research results in semi-humid areas (sub humid). The result of Kc values were conversion of cocoa from the semi-humid area to the humid area (tropics) [16]. Two soil properties that influence the availability of ground water, namely the content of organic matter and soil texture [17]. In Batu Alang village, Sabbang District, North Luwu regency, the texture of the soil was in the moderate category (dusty clay), with an average soil pH of 6.15, C-organic content of 1.78% (low category), CEC of 6.90 (cmol (+)/kg) (low category), and base saturation of 100 (very high category). Based on the chemical properties of the soil, it indicates that Batu Alang Village has a very suitable category (S1) for cocoa development. Land does not have a significant limiting factor to sustainable use, or a non-dominant limiting factor and will not significantly reduce land productivity.

3.4.2. Water requirements of cocoa plants in the North Luwu Regency. Plant water demand is influenced by various factors, one of which is air temperature. Air temperature affects the amount of water lost from the soil and plants through the evapotranspiration process, while the crop water requirement is the amount of water needed by plants to meet water losses due to the evapotranspiration process.

Higher temperatures will result in higher evapotranspiration of plants. However, plant water demand is also influenced by factors from these plants, one of which is the stage of plant development. Figure 2 shows that the temperatures at the study site in October to December were higher than in June.
to August, but the crop water requirements in those months are lower. This is caused by the stages of development of these plants. In general, the water needs at the initial stage of flower bud emergence (stage 1) was lower and then increased in the next stage, namely the flowering stage until the fruit appears (stage 2). Maximum plant water demand occurred at the fruit filling stage (stage 3) and decreased at the fruit ripening stage until the harvest period (stage 4).

![Figure 2. Relationship between the monthly air temperature and crop water requirement of cocoa plants in North Luwu Regency. CWR = Crop Water Requirement.](image)

Crop water demand in September-December was higher than in May-August, because the majority of the rainy season is from May to August. Meanwhile, the September-December period consisted of the majority of the dry season. In the dry season, water needs are high because the soil does not have enough water available for plants. Meanwhile, in the rainy season, water is available in the soil that can be utilized by plants quite a lot due to the amount of rain falling.

Crop water requirements (CWR) can be determined from the amount of crop evapotranspiration (ETc) that occurs. The greater the evapotranspiration of plants, the more water is needed to meet the lost water through the plant evapotranspiration. In general, crop water needs can be met with rainwater. However, in certain cases such as during the dry season, rain tends to fall over a short and rare period of time. This causes the plants to experience a water deficit, hence irrigation efforts are needed to meet the water deficit. So that the water deficit can be avoided, it is necessary to estimate the amount of plant water needs, which in turn can be used to estimate the amount of irrigation needed.

The recent study used Cropwat software version 8.0 issued by FAO to estimate the water needs of cocoa plants. The output of this software is plant evapotranspiration (ETc), which is the same amount as the plant's water needs. ETc refers to the amount of water lost through evapotranspiration, while crop water requirements refer to the amount of water that must be supplied to meet water losses due to evapotranspiration. Cropwat uses rainfall data (mm) to calculate effective rainfall (mm), which is then used as a determinant of irrigation needs. Meanwhile, climate data in the form of maximum and minimum temperature, relative humidity, wind speed, and solar radiation produce an output in the form of evapotranspiration (ET).

Potential evapotranspiration (ETo) is an evapotranspiration that occurs in a standard condition. In the other hand, crop evapotranspiration (ETc) is influenced by plant factors, for example the Kc value. Therefore, ETo data and crop data are reprocessed at a later stage in Cropwat and produce an output of
ETc in mm per day and mm per 10-days period. The amount of ETc is equivalent to the amount of plant water needs.

Evapotranspiration is the amount of water lost due to evaporation. The amount of potential evapotranspiration value is highly dependent on climate parameters. Therefore, for the potential evapotranspiration analysis using the Cropwat model, climate data must be available from the nearest climatology station. This is consistent with the opinion of Handoko [19], which states that the potential Evapotranspiration (ETo) as stated by Penman, is the rate of evapotranspiration from short plants that completely cover the soil, uniform height, and are in a state of sufficient water. This definition, aside from being intended to maximize the rate of evapotranspiration to obtain its potential value, also has the implication that ETo is only determined by climate factors. This is also supported by the opinion of Susilawati [13], who stated that in field conditions it is not possible to distinguish between evaporation and transpiration if the soil is covered with vegetation. The two processes are interrelated so they are called evapotranspiration. The amount of water content lost from the soil by evapotranspiration depends on adequate water supply (rain and others) and climate factors such as temperature, humidity, wind speed and others.

Plant water requirements at stage 1, the initial stage of flowering (August-October) only require a little water, because too much rainfall has the potential to knock out flower buds. The same thing also happened at stage 2, namely the stage of flower development until the flowers bloom and the fruit begins to appear (November-January), because at this stage young flowers and fruit are still prone to experiencing loss. At the stage of fruit filling or stage 3 (February-April), cacao plants need a lot of water, because in addition to distributing photosynthate to plant parts such as leaves and stems, water also needs to distribute a lot of photosynthate to parts of fruit. Water demand then decreases at the fruit ripening stage or stage 4 (May-July), because at this stage, too much water will damage the fruit's taste. Based on the output of the Cropwat software, cocoa ETc, which represents the water needs of cacao plants, ranges from 68.8 - 129.6 mm / month, while the effective rainfall in North Luwu Regency ranges from 132.2 - 166.9 mm/month (figure 3). Rainfall in North Luwu Regency is considered sufficient to be planted with cocoa, because as shown in figure 3, evapotranspiration of cacao plants (ETc) is smaller than the amount of effective rainfall (effective rainfall).

![Figure 3. Evapotranspiration of Cocoa Plants in North Luwu Regency in the 2014-2018 Period](image)

3.5. Conditions of cocoa pod borer attack in North Luwu Regency

Increase in the area of cocoa pod borer attack in the study site was directly proportional to the increase in the population of cocoa pod borer and vice versa. Area of the attack seems to be attributed to the climatic conditions in the cocoa plantation area. Some climate factors affecting the development of the
pest population, hence the area of pest attack were air temperature, humidity, and the effective rainfall. The relationship between these factors to the variation of the area of the pod borer attack are shown in figure 4, 5 and 6.

![Figure 4. Relationship between monthly average temperature and area of pest attack at North Luwu Regency in 2014-2018 period.](image)

Figure 4 indicates that the area of cocoa pod borer infestation in the 2014-2018 period varied each month. The lowest average temperatures occur in August. The number of attacks began to increase until February followed by a decline when the temperature reached a maximum. According to Jumar [20], temperature and humidity are the factors that influence the development of cocoa pod borer populations, the effective temperature for insect development is 15 °C (minimum temperature), 25 °C (optimum temperature), and 45 °C (maximum temperature), and the cocoa pod borer requires night temperature ranged from 26 to 28 °C to be well established in an area.

Changes in temperature affect the dynamics of insect populations. According to Shi et al. [21] temperature affects physiology, abundance, phenology, insect distribution, and insect dimensions. The results of Thomson et al. [22] stated that changes in temperature can affect the population and distribution of phytophagous insects (Lepidoptera) which are the orders of the cocoa pod borer. Insect population dynamics are closely related to climate, the increase in the number of cocoa pod borer populations in the North Luwu region is thought to be caused by all phases of cocoa pod borer reaching optimal temperature conditions to develop. Decrease in insect population can be caused by a decrease in fecundity due to a decrease in temperature [23].

In addition to air temperature, the development of cocoa pod borer is known to be strongly influenced by rainfall. The cocoa pod borer population is generally low during the rainy season and high attacks on shaded cocoa plants [24]. High rainy season illustrates the condition of humidity that will increase. Figure 5 indicates that the area of pest attack decreased during the rainy season in March-June, and during the dry season the area of attack increased. Rainy season is attributed to high humidity, and humidity can increase insect fecundity and fertility. The recent study reveals that at higher humidity up to 80-90%, the population of cocoa pod borer also increased. This results is confirmed by Baharudin et al. [25] who states that the conditions suitable for the development of cocoa pod borer are growing conditions under heavy shading. The 80% humidity is suggested to be the ideal humidity to support the growth and development of cocoa pod borer. Nainggolan [26]
explains that humidity fluctuations play a significant role in regulating the activity of organisms and are often a limiting factor to population dynamics and insect distribution.

![Graph showing relationship between monthly humidity and area of pest attack at North Luwu Regency in 2014-2018 period.](image)

**Figure 5.** Relationship between monthly humidity and area of pest attack at North Luwu Regency in 2014-2018 period.

![Graph showing relationship between monthly effective rainfall and area of pest attack at North Luwu Regency in 2014-2018 period.](image)

**Figure 6.** Relationship between monthly effective rainfall and area of pest attack at North Luwu Regency in 2014-2018 period.

The relationship between the extents of the attack with effective rainfall is shown in figure 6. Effective rainfall increased in the April-June period and decreased in July-September. While the extent of attacks increased in February with an effective rainfall of 155.8 mm. Cocoa pod borer populations are generally low in the rainy season and high in the dry season until the next rainy season. Heavy rainfall seems to affect the moth mobility. Towards the dry season, in line with the increasing number of large-sized fruit, the population of cocoa pod borer increases rapidly [27]. However, in the dry months, the intensity of cocoa pod borer attacks is reported to be lower than in months with normal...
rainfall. Likewise, cocoa planting with light shade or without shade is less attacking than planting with complete shade. The area of attack is directly proportional to the level of population, the wider the attack, the higher the level of cocoa pod borer populations.

There are several factors that influence the level of cocoa pod borer populations, namely the existence of secondary pest outbreaks. The use of pesticides intended to eradicate certain types of pests, can even cause the emergence of other types of pests. The secondary pest outbreak can occur shortly after the use of pesticides, or at the end of the growing season or even the next planting season. Secondary pest outbreaks can be more damaging than previous target pests [28]. Pest control by breaking the life cycle of cocoa pod borer, such as frequent harvesting, attacked fruit sanitation and utilization of imago traps. From the data obtained, farmers harvest in April-June, which indicates the lack of widespread cocoa pod borer infestation. Whereas the temperature / humidity conditions indicate an ideal environment for increasing pest populations.

4. Conclusions

Based on the research results obtained, it can be concluded as follows:

- Evapotranspiration of cocoa (ETc) at stage 1 is 106.53, stage 2 is 114.2, stage 3 is 106.2, and stage 4 is 85.1. Rainfall in North Luwu Regency is classified as sufficient for cocoa as ETc is smaller than the effective rainfall in this area.
- Climate factors influence the extent of cocoa pod borer attack. The highest area of cocoa pod borer infestation occurred in February attributable to climatic conditions with an average temperature of 27.2 °C, humidity of 81%, rainfall of 308 mm with an area of 8332 ha and the lowest in May with an average temperature of 27.4 °C, humidity 83%, rainfall of 384 mm with an area of 3224 ha.

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