Management of planting system based on water balance patterns on corn plants using Cropwat 8.0 model

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Abstract. Corn plants are the second most important food crop after rice; however, climate anomalies will affect the amount of production that is related to the water requirements available during the process of growing corn plants. This study aims to determine the amount of effective rainfall in one year and the need for irrigation water in one planting season, the water requirements for maize in a particular planting period and the comparison of the rate of evapotranspiration and the level of water that must be available to plants. This research was conducted from May to September 2014 at the Agricultural Technology Research Institute (BPTP) of South Sulawesi, Gowa Regency. The data obtained in the field was then processed using the simulation method of a Windows-based application, Cropwat 8.0. The results show that the water needs of corn plants in each growth phase are: 107 mm/decade in the early development phase, 132.9 mm / decade in the mid-phase, and 107.4 mm / decade in the late phase. The amount of rain data for a year in 2014 obtained using Cropwat was 395.6 mm, and the effectiveness of the rain that occurs was 355.9 mm. These figures then used to determine the irrigation water needs for one growing season.

1. Introduction

Corn is the second staple food after rice in Indonesia. Based on the order of staple foods in the world, corn ranks third after wheat and rice. As a food ingredient, corn contains nutrients needed by the human body in large quantities. Also, corn can be used for animal feed, as well as basic industrial materials such as food, beverages, flour, oil, and others; therefore, production needs to be increased [1]. Indonesia, as an archipelagic country located in the equator, includes areas that are very vulnerable to climate change. Changes in rainfall patterns, sea-level rise, and air temperature, as well as an increase in extreme climate events in the form of floods and droughts, are some of the serious effects of climate change faced by Indonesia. Anomalies or climate deviations are estimated to continue to threaten agricultural production systems, and can even lead to crop failure.

Since the climate is one of the main elements in the metabolic system and plant physiology, global climate change will adversely affect the sustainability of agricultural development [2]. Climate anomalies cause changes in the amount of rain and rain patterns that result in a shift at the beginning of the season and planting period. The decrease in rainfall has reduced the potential of one corn...
planting period. Therefore, to increase or maintain production, the problem of water crisis must be considered.

Maize is a medium water-use plant, ranging from 400-500 mm [3]. However, corn cultivation is constrained by the unavailability of water in the right amount and time. Especially in lowland rainfed lowland areas, the excess amount of soil moisture in the soil will still disrupt plant growth. Meanwhile, delaying planting time will cause a lack of water stress in the growth phase until seed formation. Therefore, water management technology is needed for corn plants [4]. The anticipation of climate anomalies can be done by adjusting the modification of inputs to reduce climate risk and behavior by conducting an accurate analysis of forecasting, flood and drought early warning systems, determining the planting period, supported by the ability to disseminate climate forecasts and anticipate technology quickly and accurately to users [5].

One way to overcome this problem is to calculate the water needs of corn plants so that the water supply meets the plant's requirement. Water is needed by plants to replace water lost through the process of transpiration and evaporation, collectively, generally referred to as evapotranspiration. Equilibrium between water entering the soil and being lost through the evapotranspiration process can be shown in the water balance. Water balance is a balance of inputs and outputs of water in a place for a certain period so that it can know the amount of water that is surplus or deficit. The use of knowing the condition of water in surplus and deficit can anticipate disasters that might occur, and can also be used to make the best use of water. Quantitatively, the water balance illustrates the principle that during a certain time, the total water input is equal to the total water output coupled with a change in storage. The value of this reserve water change can be marked positive or negative [6].

The concept of the water balance shows the balance between the amount of water entering the land available on the land and that which comes out of a particular system (subsystem). In general, the water balance equation is formulated by [7].

\[ I = O \pm \Delta S \]  

where:

- \( I \) = inflow
- \( O \) = outflow

In calculating water balance factors that need to be considered, including the capacity to store water (the amount of pore space), infiltration, runoff, evapotranspiration, rainfall, and vegetation types. A plant coefficient is needed to obtain the actual evapotranspiration value; thus the plant coefficient will be very useful in predicting water requirements for plant growth [8]. Information about the value of crop water requirements (crop water requirements), especially water requirements for each level of plant growth is still very lacking. Therefore research to determine the value of plant water needs is necessary. One way to find out the water needs of plants is to use Cropwat. Cropwat is a Windows-based program that is used to calculate plant water requirements and irrigation needs based on land, climate, and plant data. This program allows the development of irrigation schedules for different management conditions and schemes for calculating water supply for plants of various patterns. Cropwat can be used to calculate potential evapotranspiration, actual evapotranspiration, irrigation water needs for one type of plant and several types of plants and plan for the provision of irrigation water [9]. Cropwat 8.0 can be used as a tool to calculate plant water requirements and irrigation water based on soil data, climate, and data on plants to be planted.

The most careful method for estimating the magnitude of evapotranspiration from a surface covered by plants is through a simulation process of a combination of unsaturated flow in the soil with evapotranspiration. The approach was taken based on the adaptation of Monteith to the Penman formula. Detailed and rigorous situations of meteorological data needed are difficult to obtain. Therefore estimation in the calculation of actual evapotranspiration and potential evapotranspiration is sufficient [10]. If the available water supply cannot meet plant water requirements, or \( ET_a < ET_m \),
plants will show different responses to this water deficit. In some plants there will be an increase in water use efficiency, while in other plants the efficiency of water use decreases with increasing water deficit. If water deficits occur during a certain time in the crop growing season, the yield response to water deficits varies greatly depending on the sensitivity of the plant in that period. In general, plants are very sensitive to water deficits during the initial growth, flowering, and the beginning of the phase of formation of results [11].

If the water supply is insufficient to meet the needs of the plant, the actual evapotranspiration (ETa) will decrease below the maximum evapotranspiration (ETm) or ETa < ETm. Under these conditions, stress will develop in plants that will adversely affect plant growth and yield. The effect of the intensity and time of stress is very important concerning the scheduling of limited water supply during the period of plant growth and prioritizing the use of water supply between plants during the growing season [11].

2. Methodology
This research was carried out in the Institute for Agricultural Technology Studies (BPTP) in Gowa Regency. This research was conducted from May to September 2014 using a survey method with data collected consisted of climate data for the past five years including irradiation time (hours), rainfall (mm), maximum temperature (°C), minimum temperature (°C), air humidity (%), and wind speed (km/day) obtained from nearest climate station. Water balance is calculated based on the last five years of rainfall data to determine the planting time of corn plants based on the occurrence of the rain. Data on maximum temperature, minimum temperature, air humidity, wind speed, solar radiation were analyzed to determine the amount of ETo, while rainfall data is used to determine the amount of effective rainfall that occurs. Processed data was input into Cropwat 8.0 and subsequently, run for a simulation to determine the water requirements of corn plants.

3. Results
3.1. Rainfall Data Analysis
The input of rainfall data with Cropwat model produces effective rainfall calculations. Table 1 shows the processing of monthly rainfall data that produces effective rainfall. From the table, it can be seen the highest rainfall intensity falls in January and the lowest rainfall falls in August.

| Month   | Rain (mm) | Effective rain (mm) |
|---------|-----------|---------------------|
| January | 114.8     | 93.7                |
| February| 67.4      | 60.1                |
| March   | 49.4      | 45.5                |
| April   | 35.8      | 33.7                |
| May     | 12.1      | 11.9                |
| June    | 2.5       | 2.5                 |
| July    | 9.9       | 9.7                 |
| August  | 3.4       | 3.4                 |
| September| 14.2    | 13.9                |
| October | 17.5      | 17.0                |
| November| 23.1      | 22.2                |
| December| 45.5      | 42.2                |
| Total   | 395.6     | 355.9               |
3.2. Plant Water Requirement

Plant water needs can be determined based on the value of plant evapotranspiration (ETc). Table 2 shows the results of calculation of water requirements for corn plants based on plant evapotranspiration accompanied by a calculation of irrigation water requirements. From the table, it can be seen that the largest evapotranspiration and the highest irrigation water needs occur in the mid-phase (seed filling phase) precisely in the 3rd decade of July.

Table 2. Calculation of the water needs of corn plants per decade and irrigation water needs

| Month | Decade | Stage | Kc | ETc | ETc | Eff. rain | Irr. Req. |
|-------|--------|-------|----|-----|-----|----------|----------|
|       |        |       |    | Coeff | mm/day | mm/dec | mm/dec | mm/dec |
| May   | 3      | Deve  | 0.52 | 2.17 | 10.8 | 1.2 | 9.6 |
| Jun   | 1      | Deve  | 0.62 | 2.60 | 26.0 | 1.4 | 24.6 |
| Jun   | 2      | Deve  | 0.74 | 3.19 | 31.9 | 0.1 | 31.8 |
| Jun   | 3      | Deve  | 0.86 | 3.83 | 38.3 | 1.1 | 37.1 |
| Jul   | 1      | Mid   | 0.93 | 4.25 | 42.5 | 2.8 | 39.7 |
| Jul   | 2      | Mid   | 0.93 | 4.38 | 43.8 | 3.8 | 39.9 |
| Jul   | 3      | Mid   | 0.93 | 4.24 | 46.6 | 2.9 | 43.7 |
| Aug   | 1      | Late  | 0.90 | 3.99 | 39.9 | 1.3 | 38.6 |
| Aug   | 2      | late  | 0.76 | 3.23 | 32.3 | 0.4 | 31.9 |
| Aug   | 3      | Late  | 0.58 | 2.49 | 27.4 | 1.8 | 25.6 |
| Sep   | 1      | Late  | 0.46 | 1.96 | 7.8  | 1.5 | 6.0  |
| Total |        |       |     | 347.3 | 18.4 | 328.5 | |

Data processed by Cropwat 8.0.

Figure 1 shows the level of evapotranspiration and irrigation water requirements of maize plants. Based on the graph, the plant started to conduct evapotranspiration from land preparation and continues to increase until it reaches a peak in July of the second decade and slowly decreases until the lowest evapotranspiration occurs in the 1st decade in September (final phase). Meanwhile, the biggest irrigation water needs occur in the 3rd decade of July, when the plants enter the mid-phase (fertilization phase) and slowly decline, until August until finally reaching the harvesting process. The amount of evapotranspiration that occurs will result in how much irrigation water is needed.
Figure 1. Graph of the relationship between evapotranspiration and plant water requirements resulted from Cropwat 8.0. Dec. = decade.

4. Discussion

The results of rainfall analysis will produce effective rainfall. Effective rainfall is rain that is effectively used by plants to meet their water needs (Table 1). Figure 1 shows that the highest rainfall intensity occurred in January, which was 114.8 mm, and the lowest rainfall occurred in August. Although the intensity of rainfall was high in January, the effective rainfall used by plants was only 93.7 mm of the total amount of rain that fell. Unlike January in June to August, where the rainfall intensity is low, almost all falling rain will be effective rain for plants. High rainfall will be effective rain for plants according to plant needs. However, not all of the available rainfall is absorbed by plants, and some will lost for runoff and percolation. According to Susilawati [10], the plants do not use all falling rainfall and some rain lost due to runoff or because deep percolation is far outside the root area of the plant.

Plant water requirements are determined based on the calculation of effective rainfall, besides depending on rainfall, it also depends on potential evapotranspiration and plant data, namely plant coefficient and plant growth stage. Based on the results of the analysis in Table 2, plant evapotranspiration continues to increase along with its growth stage and slowly begins to decline after the plant reaches maximum growth. The increase is because plant evapotranspiration is directly proportional to the plant coefficient. In this case, the plant coefficient describes the rate of water loss by plants during the growth stage. So that when the plant coefficient decreases, plant evapotranspiration will decrease. The Actual Evapotranspiration is the thickness of water needed to replace the amount of water lost through evapotranspiration in healthy plants [4]. The value of Estimated Transmitting Ability (ETA) is the value of water needs that must be given to plants or is the basis for determining water requirements for plants in the field.

In the initial phase of growth, water is needed by corn plants to grow and develop. Whereas in the development phase, water is needed by plants for stem formation to reach maximum growth. At the end of the development phase and the beginning of the middle phase, the plant prepares a lot of energy reserves for the flowering process. Thus at the end of the development phase, the highest evapotranspiration was 46.6 mm/decade. High evapotranspiration values indicate the amount of water
needed by plants. According to Soemarno [11], plants are generally very sensitive to water deficits during the initial growth, flowering, and the beginning of the phase of formation of results.

In addition to calculating the water needs of the Cropwat model can also calculate irrigation water requirements for each stage of plant growth. Table 5 indicates that the need for irrigation water to obtain a high yield in the corn plant is from in each phase starting from land preparation and the initial phase of plant growth, phase of seed filling and yield phase but the water demand will gradually decrease when it enters in the final phase. The requirement is due to high evapotranspiration factors; besides that, other factors that influence the requirement are soil treatment and the effectiveness of the rain that occurs. So that water is only needed in large quantities during land preparation, at the initial phase, and seed development and seed filling. Suherman [12] suggested that water requirements in plants depend on the type of plant and its growth phase, soil type, and climatic conditions.

5. Conclusion

- The water needs of corn plants for each phase of growth, namely, development phase (development) 107 mm / decade, mid-season (midpoint) 132.9 mm / decade, and late season (final) 107.4 mm / decade.
- The amount of rain for one year was equal to 395.6 mm, and the effectiveness of the rain that occurs was 355.9 mm so that it can bring up how much irrigation water needs are needed.
- The effect of evapotranspiration on water needs is very large because in this planting period the rate of evapotranspiration is directly proportional to the water requirements so that the higher the evapotranspiration that occurs, the higher the water needed.
- Corn planting that will be carried out in the dry season should be in areas that have irrigation because the water need for corn is also high for the growth phase until at the time of fertilization. Also, corn planting should not be carried out in months that have low rainfall because it is not enough to meet the water needs of plants.

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