Adjusting planting time using water balance and rainfall prediction approaches

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Abstract. The appropriate planting time is an alternative to avoid loss yield and increase the production of food crops. The objectives of this study were to analyze water balance for adjusting the proper planting time was carried out in three locations with different rainfall patterns and groundwater capacities. The analysis was performed using the water balance approach. Input data used are rainfall prediction potential evapotranspiration and groundwater storage capacity. The results showed that the water balance analysis in Bandar Sidoras Irrigation Area with an equatorial rainfall pattern has a water surplus period of 2 to 3 months longer than the Mrican Kanan and Gadungan Lambuk Irrigation Area, which have a monsoon rainfall pattern. However, the potential cropping pattern applied in each Irrigation Area is the same, Rice-Rice-Maize/Soybean, with the first planting season in Gadungan Lambuk in earlier of May to August. In comparison, the first planting season in the other two irrigation areas is from November to February. The water balance and rainfall prediction approaches are appropriate for determining optimal growth and development of food crops.

1. Introduction

The success of agricultural production, especially food crops, is dependent on climatic conditions for the growth and development of food crops [1]. Climate variability plays a vital role in determining plant growth, development, and yield through linear and non-linear responses to weather variables and exceedances of well-defined crop thresholds, particularly temperature and rainfall in the tropics [2,3]. Climate affects four components of food security such as food supply, food access, the use of foodstuffs, and resilience of the food production system [4]. Recently, there was a great deal of neglect in the relationship between environment, cultivations, soil and water use improvements associated with agricultural practices [5,6]. Climate change is strongly affecting the food system in various ways ranging from direct effect on crop production [4].

A changing climate leads to the frequency, duration, and intensity of climate extremes. The El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) phenomena have an impact on changes in distribution patterns, intensity, and periods of the rainy season so that the start of the rainy season and the dry season becomes late [7-9]. As a result, there is a shift in the season from its normal average conditions, which can have severe implications for rice crops [10,11] and other food crops. The impact of these phenomena is also very pronounced on changes in cropping patterns in both irrigated and rainfed lowlands. At present, most of the rice planting area uses the rice-paddy cropping pattern, wherein the second planting season is highly dependent on the availability of irrigation water [8]. The drought in the second planting season will change the cropping pattern from rice to non-rice to decrease of rice production, which will disrupt the sustainability of the national rice stock.
Lack of water can inhibit plant growth and even risk cause the death of plants. Information on water availability is needed to adjust cropping patterns according to groundwater conditions. Therefore, a significant effort is required for planning the planting times through the water balance approach and rainfall prediction information. Information on water availability can be obtained through land water balance calculations using the bookkeeping system [12]. The groundwater balance requires input data such as rainfall, evapotranspiration, and available water values. In this study, the monthly rainfall data used is a combination of observation data with satellite data [13]. At the same time, evapotranspiration data is also grid data, which is a combination of observation data with satellite data [14]. For data on the capacity of groundwater availability, it is a combination of raster data between observation data and satellite data [15].

This study aims to analyze the planting time using the water balance approach in three locations with different rainfall amounts and patterns and groundwater capacities.

2. Materials and methods

2.1. Study area
The study was conducted in three locations with different rainfall amounts and patterns and also various groundwater capacities using rainfall data, evapotranspiration data, available water value data and water balance calculations. The sites are: (1) The Bandar Sidoras Irrigation Area, irrigation service area located in Percut Sei Tuan District, Deli Serdang Regency, North Sumatra Province; (2) The irrigation service area of Irrigation Area Mrican Kanan located in Megaluh District, Bandar Kedung Mulyo District, Perak District in Jombang Regency and Purwosari District, Papar District, Kayen Kidul District, Gampeng Rejo District in Kediri Regency, East Java Province; (3) The irrigation service area of Gadungan Lambuk in Kerambitan District and Selemadeg District, Tabanan Regency, Bali Province (figure 1).

2.2. Data preparation
This research requires rainfall data, evapotranspiration data, and available water value data. The rainfall data used comes from the CHIRPS data (Climate Hazards Group Infra-Red Precipitation with Station data) for the period 1990 to 2019 (https://iridl.ldeo.columbia.edu/SOURCES/.UCSB/.CHIRPS/). CHIRPS is gridded data rainfall with a resolution of 0.05° x 0.05°, which is a combination data between observation data and satellite data [13].
Evapotranspiration data were obtained from the CRU (Climate Research Unit) for the period 1990-2019 (https://crudata.uea.ac.uk/cru). CRU is also a grid data with a resolution of 0.5° x 0.5°, which is a combination of observation data with satellite data [14]. The last data is rice and maize coefficient data obtained from the literature [16]. Then available water capacity data (AWC) is obtained from Soil grids. Soil grids are raster data with a resolution of 250 x 250 meters, which is a combination of observation data with satellite data (https://iridl.ldeo.columbia.edu/SOURCES/.SoilGrids/).

2.3. Water balance analysis
Water balance calculations require supporting data such as monthly rainfall data, evapotranspiration data, available water value data, and coefficient values for rice and maize crops. The water balance calculation method used in this research is bookkeeping system water balance method [12]. The procedure for calculating the water balance is as follows:

1. Row-1: Monthly rainfall data (R)
2. Row-2: Inundation of land
3. Row-3: Identify the planting period
4. Row-4: Potential evapotranspiration data (PET)
5. Row-5: The coefficient value of rice and modified maize (Kc)
6. Row-6: ETc (mm)
   \[ ETc = PET \times Kc \]  

7. Row-7: Difference between rainfall value and ETc (R-ETc)
8. Row-8: Accumulated Point of Water Loss (APWL)
   \[ APWL = \begin{cases} 0 & \text{if } CH-PET \geq 0 \\ \sum |R-PET|_{\text{negatif}} & \text{if } R-PET \leq 0 \end{cases} \]
9. Row-9: Soil moisture water content (ST)

\[ ST = AWC \times \left( 1.00041251 - \frac{1.073807306}{AWC} \right)^{APWL} \]  

(3)

10. Row-10: Changes of soil moisture

\[ \Delta ST = ST_i - ST_{i-1} \]  

(4)

Changes of soil is calculating by subtracting soil moisture current month (ST\(_i\)) to soil moisture previous month (ST\(_{i-1}\))

11. Row-11: Actual Evapotranspiration (AE)

\[ APWL = \begin{cases} 
AE = ETC, & \text{if } R > ETc \\
AE = R - \Delta ST, & \text{if } R < ETc
\end{cases} \]  

(5)

12. Row-12: Deficit = ETc - ETa

13. Row-13: Surplus

\[ \text{Surplus} = \begin{cases} 
0, & \text{if } R - ETc < 0 \\
R - ETc - \Delta ST, & \text{if } R - ETc > 0
\end{cases} \]  

(6)

3. Results and discussion

3.1. Bandar sidoras irrigation area, Deli Serdang, North Sumatra

The study location in the irrigation area of Bandar Sidoras has an average rainfall of 2,126 mm year\(^{-1}\) with a bimodal or equatorial rainfall pattern. The lowest rainfall in third of ten days period (decad) in February, which was 21 mm, and the highest rainfall value 109 mm on third of September. According to the Oldeman agro-climatic zone classification, the irrigation area of Bandar Sidoras in zone C2 with five wet months, and two dry months have an average air temperature of 27\(^\circ\)C to 29\(^\circ\)C.

The results of the water balance analysis show that the Bandar Sidoras irrigation is in a surplus condition for eight months in the May to December period, rainfall above 100 to 150 mm month\(^{-1}\) in these months can meet crop water requirements. Conversely, in the January to April period, the amount of rainfall decreased, with the result that the availability of water in the land becomes deficit. This condition causes insufficient water availability for the evapotranspiration process (figure 2).

Based on the results of land water balance analysis, the recommended cropping pattern to be applied in the Irrigation Area of Bandar Sidoras is rice-rice-maize/soybean. The first planting season (PS-I) is recommended in the May to August period along with the arrival of the beginning of the rainy season or the beginning of the wet period (table 1). In PS I, there is a groundwater surplus from 10 to 50 mm month\(^{-1}\) until more than 100 mm month\(^{-1}\) (figure 3a), so that the water is more than sufficient for cultivating rice. However, it is necessary to schedule the provision of irrigation water in May to June that needs 50 mm month\(^{-1}\) for water requirements (figure 3b).

The PS-II is recommended in the September-December period. In PS II, there is a surplus of groundwater more than 100 mm month\(^{-1}\), so that the water is more than sufficient for cultivating rice. In the second planting season, it is necessary to schedule irrigation water for the inundation of rice plants in September to October at 50 mm month\(^{-1}\) for two months.
The third planting season is recommended in the January to March period. In the third planting season (PS III), cultivating maize is recommended because there is less water condition for rice. In January, there is still a groundwater supply of 10 to 50 mm month\(^{-1}\), but in February, there is a groundwater deficit of 50 to 100 mm month\(^{-1}\) to reach field capacity. From March to April, there is an increase in rainfall, so that the groundwater deficit is less than 10 mm month\(^{-1}\) to reach field capacity condition. Crop water requirement for maize is sufficient on PS III if irrigated with 14 mm month\(^{-1}\) in February. Thus, it is hoped that the planting conditions will be optimum due to adequate water availability. If in PS III, the additional water of 14 mm month\(^{-1}\) can not be fulfilled, then farmers can still plant corn with the risk of decreasing yields. It is replaced with other commodities that require lower water, for example, green beans or sweet potatoes.

| Planting Season | Periode     | Plantation      | Total Water Surplus (mm) | Total Water Deficit (mm) | Total Water Requirement (mm) |
|-----------------|-------------|-----------------|--------------------------|--------------------------|-----------------------------|
| PS-I            | May - Aug   | rice            | 291                      | 0                        | 100                         |
| PS-II           | Sept - Dec  | rice            | 671                      | 0                        | 100                         |
| PS-III          | Jan - Mar   | maize/soybean   | 64                       | 60                       | 14                          |
3.2. Mrican Kanan irrigation area, East Java.

The Mrican Kanan irrigation area has an average rainfall of 3,301 mm year\(^{-1}\) with a monomodal or Monsoonal rainfall pattern. The lowest rainfall on the 2\(^{nd}\) decad of August, which has 3 mm month\(^{-1}\), and the highest rainfall on the 3\(^{rd}\) decad of January, with 240 mm month\(^{-1}\). According to the Oldeman agro-climatic zone classification, the Mrican Kanan irrigation area is in the B\(_3\) agro-climate zone with 7 wet months and 5 dry months. The average air temperature is 23\(^{\circ}\)C to 25\(^{\circ}\)C. The rainy season in the period from November to May, when the west wind blows from the Indian Ocean, containing a lot of water vapor. The dry season in the period May to October, coinciding when the east wind blows from Australia, which is dry and has little water vapor.

The results of the water balance analysis illustrate that Mrican Kanan irrigation area has seven months of water surplus in the November to May period (figure 4). This is because high rainfall occurs in these months so that the availability of water in the land can meet the needs of plants for the evaporation process (PET and AE). On the other hand, during the June to September period, there was a condition of low rainfall so that the availability of water in the land decreased until it reached a deficit condition. Rainfall rises again in October, and then a surplus started to occur in November.

![Graph of the Balance of Rainfall and Potential and Actual Evapotranspiration in Mrican Kanan Irrigation Area](image)

**Figure 4.** Water Balance for Mrican Kanan irrigation area.

Based on land water balance analysis, the recommended cropping pattern to be applied in the Mrican Kanan irrigation area is paddy-rice-rice-maize/soybean. The first planting season (PS-I) is recommended in the November to February period along with the onset of the rainy season (table 2). In PS-I, there was a surplus of groundwater up to 100 mm month\(^{-1}\), so that the water is surplus to cultivate the rice. However, it is necessary to schedule irrigation water for the inundation of rice plants in November-December at 50 mm month\(^{-1}\) for two months.

The second planting season (PS-II) is recommended in the period March to June. In PS-II, the water is sufficient for cultivating with the water surplus is 0-10 mm month\(^{-1}\), 10-50 mm month\(^{-1}\), 50-100 mm month\(^{-1}\) and more than 100 mm month\(^{-1}\). In the second planting season, it is necessary to determine the provision of irrigation water for the inundation of rice plants in March to April at 50 mm month\(^{-1}\) for two months. The third planting season is recommended in the July to September period (figure 5).

In PS-III, it is recommended to cultivate maize/soybean due to water deficit conditions. In July and September, there is a groundwater deficit of 10 to 50 mm month\(^{-1}\), but in August, groundwater deficit reaches more than 100 mm month\(^{-1}\) to get a condition of field capacity. To guarantee the growth of maize plants to the optimum condition of the plant, additional irrigation water needed is 9 mm month\(^{-1}\) in July and 16 mm month\(^{-1}\) in August to September. Thus, the total water requirement for optimum groundwater conditions for planting is 41 mm during the growing season. If in PS-III the additional 41 mm of water cannot be fulfilled, it is advisable to fall.
Figure 5. Surplus and deficit period (a) and water demand (b) in the irrigation area of Mrican Kanan.

Table 2. Planting Time for the Mrican Kanan irrigation area.

| Planting Season | Periode  | Plantation       | Total Water Surplus (mm) | Total Water Deficit (mm) | Total Water Requirement (mm) |
|-----------------|----------|------------------|--------------------------|--------------------------|-------------------------------|
| PS-I            | Nov - Feb| Rice             | 685                      | 0                        | 100                           |
| PS-II           | Mar - Jun| Rice             | 282                      | 0                        | 100                           |
| PS-III          | Jul - Sep| Maize/soybean    | 0                        | 201                      | 41                            |

3.3. Gadungan lambuk irrigation area, Bali

The Gadungan Lambuk irrigation area usually has a moist tropical climate. The average annual precipitation is between 2,155 and 3,292 mm of monomodular or Monsoonal precipitation patterns. The rainy season in November to May is characterized by heavy rainfall. From April to September, the dry season takes place. The temperature ranges from 24°C to 27°C and high level of humidity is from 74 to 77 percent. The Gadungan Lambuk irrigation area is included in the C and D forms of rain in compliance with the Schmidt and Ferguson classifications [17].

The water balance analysis indicates that the irrigation field of Gadungan Lambuk has a water surplus of 6 months in the period from November to April. In these months, high precipitation leads to water availability is sufficient for the crop requirements (PET and AE) during the evaporation process. On the other hand, the rainfall decreased in the April to September period, thus reducing land water supply to a deficit. Rainfall is surplus in October and November (figure 6).

Based on land water balance analysis, the recommended cropping pattern applied in Gadungan Lambuk is rice-rice-maize/soybean. The first planting season (PS-I) is recommended in the November-February period, along with the arrival of the beginning of the rainy season or the beginning of the wet period (table 3). In PS I, there is a surplus of groundwater up to 100 mm month\(^{-1}\), so that the water is more than sufficient for cultivating rice. However, it is necessary to schedule irrigation water for the inundation of rice plants in November to December at 50 mm month\(^{-1}\) for two months. The second planting season (PS-II) is recommended in the period March to June.

In PS II, there is a groundwater surplus of 0 to 10 and 50 to 100 mm month\(^{-1}\), so that the water is still sufficient for cultivating rice. In the second planting season, it is necessary to schedule irrigation water for the inundation of rice plants in March to April at 50 mm month\(^{-1}\) for two months. The third planting season is recommended in the July-September period (figure 7).

In PS III, it is recommended to plant maize because there is less water condition. In July, there is still a groundwater surplus of 10 to 50 mm month\(^{-1}\). Still, in August, there is a groundwater deficit of 50 to 100 mm month\(^{-1}\), and in September, there is a groundwater deficit of 10 to 50 mm month\(^{-1}\) to reach the Field Capacity condition. To be able to guarantee the growth of maize to the optimum condition of the
plant, additional irrigation water of 16 mm month\(^{-1}\) is required in August to September. Thus, the total water requirement for optimum groundwater conditions for planting is 32 mm during the growing season.

![Figure 6. Water balance for Gadungan Lambuk irrigation area.](image)

![Figure 7. Surplus and deficit period (a) water demand (b) in the irrigation area of Gadungan Lambuk.](image)

### Table 3. Planting time for the Gadungan Lambuk irrigation area.

| Planting Season | Periode   | Plantation   | Total Water Surplus (mm) | Total Water Deficit (mm) | Total Water Requirement (mm) |
|-----------------|-----------|--------------|--------------------------|--------------------------|------------------------------|
| PS-I            | Nov - Feb | Rice         | 884                      | 0                        | 100                          |
| PS-II           | Mar - Jun | Rice         | 256                      | 0                        | 100                          |
| PS-III          | Jul - Sep | Maize/soybean| 0                        | 160                      | 32                           |

### 4. Conclusions

The Bandar Sidoras irrigation area with an equatorial or bimodal rain pattern has a water surplus period for nine months in May to January and a deficit of groundwater for one month in February. These conditions indicate the potential for planting times to be 2 to 3 months longer than the Mrican Kanan and Gadungan Lambuk Irrigation Area, which have a monsoon rainfall pattern. Groundwater is surplus for six and seven months, respectively, in November to May and November to April in the Gadungan Lambuk and Mrican Kanan irrigation area. Water deficit occurred for 3 and 4 months from June to
September and August to October for the Mrican Kanan and Gadungan Lambuk irrigation areas, respectively.

In the irrigated area of Bandar Sidoras, during the planting season PS-III, if the additional 14 mm of water is not sufficient, the farmers can still plant corn/soybeans with the risk of decreasing crop yields. It could be replaced with other commodities, which require less water, such as green beans or sweet potatoes. Whereas, in the Mrican Kanan irrigation area and the Gadungan Lambuk irrigation area, if during the planting season PS-III, the additional water in the planting season of 41 mm or 32 mm cannot be fulfilled, it is advisable not to plant/fallow.

The water balance and rainfall prediction approaches are appropriate for determining optimal growth and development of food crops.

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