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Assessment of Rice Crop Water Requirements for Planting Season in Moderate Agroclimatic Area of West Sumatra

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ABSTRACT

In changing climate, uncertainty in rice production becomes more frequent leading to threat of food security. However, research on rice cultivation in the rainfed agricultural areas of West Sumatra remains limited. The objectives of the study are to analyze the crop water requirements of rainfed rice and to determine rice planting patterns. The study was conducted in a moderate agroclimatic area of West Sumatra based on oldeman agroclimatic zone that experienced changes in planting patterns. We used climate data for 1991 – 2020 obtained from TerraClimate, which were utilized for monthly water balance computation based on the Thornwhite and Matter approach. The analysis focused on four major rice production centers, namely: Panti in Pasaman, Lima Kaum in Tanah Datar, Luak in Lima Puluh Kota and Sijunjung. The results showed change in water deficit periods across the study sites have changed planting season. Based on our analysis site in Lima Kaum, Tanah Datar experienced the longest deficit period, which lasted 5 months from May to September. This situation may not suitable to plant rice throughout the year without additional irrigation. Further, adjusting to the secondary crop may be considered to optimize agricultural productivity. These findings can serve as a reference for determining planting seasons and improving water use and distribution strategies in rainfed agricultural systems.

KEYWORDS
climate variability, crop production, planting pattern, rainfed agriculture, water balance

1. INTRODUCTION

Agricultural productivity is influenced by multiple factors, including climate and soil, which together determine crop yields (Rezaei et al., 2023). While soil conditions remain relatively stable over long periods, climate is more dynamic, changing with the seasons, sea-land interactions, and global warming. One of the most significant climate-related challenges is the spatial and temporal variability of rainfall, which directly affects planting seasons. However, understanding the local-scale influence of rainfall on rice yields and planting patterns in West Sumatra remains a research challenge. In addition to rainfall, other factors affecting rice production include soil fertility, humidity, fertilizer use, seed selection, farming methods, and pest outbreaks (Al-hashimi, 2023).

Several studies have demonstrated that rainfall and air temperature significantly influence rice productivity, as observed in Banten, West Java, and

India. Additionally, large-scale climate systems such as the El Niño-Southern Oscillation (ENSO) play a critical role in determining rainfall variability over the tropical maritime continent. During El Niño events, reduced rainfall leads to water shortages, negatively impacting rice production. The WMO (2024) reported that 2023 was the warmest years on record, with a global average surface temperature of 1.45°C (±0.12°C) above the pre-industrial baseline. As global temperatures rise, shifting rainfall patterns have become more apparent, causing wet seasons to become wetter and dry seasons drier. These climatic changes influence rice production by altering planting schedules and water availability.

The impact of climate anomalies on agriculture in West Sumatra has been evident in past ENSO and Indian Ocean Dipole (IOD) events. In 2015 and 2019, El Niño coincided with a positive IOD, resulting in severe agricultural droughts. Data from rice production centers showed that 1,062 hectares of rice fields in West Sumatra suffered crop failure in 2015, while 36 hectares were affected in 2019 (Kementerian Pertanian, 2024). The worst-hit areas in 2015 were Lima Puluh Kota (361 hectares) and Tanah Datar (692 hectares), whereas in 2019, crop failures were reported in Tanah Datar (28 hectares) and Sijunjung (5 hectares) (Badan Pusat Statistik Sumatera Barat, 2024). These variations highlight the vulnerability of rice production to shifting climate patterns. However, there remains a research gap in understanding the correlation between global climate indices, such as sea surface temperature (SST) anomalies, and local cropping patterns (Nugroho and Nuraeni, 2016).

To mitigate the impacts of climate variability on agriculture, researchers have proposed solutions such as water balance modeling to estimate water availability for agricultural planning (Djufry, 2012). TerraClimate data with high spatial-resolution of (~4 km) was were in the study from 1958 to 2023. These dataset can support data-driven decision-making for agricultural adaptation strategies.

Long-term changes in West Sumatra's agroclimate zones have already been observed, particularly in rainfed farming systems. Between 1941 and 2015, shifts in rainfall patterns altered rice water requirements and planting feasibility (Saputra et al., 2018). Our study area falls under a moderate agroclimatic type, receiving an annual rainfall ranging from 1,500 to 2,500 mm (Susanti et al., 2021), which is of importance for rice production in West Sumatra.

This study aims to analyze the water needs of rainfed rice fields to provide a scientific reference for determining optimal planting seasons and developing adaptation strategies to improve rice production in response to climate variability.

Table 1. Characteristics of the four study sites

Rain Gauge	**Coordinate**	**Period of Data**	**District**	**Altitude (msl)**	**Paddy Area (1000 Ha)**	**The Peak of Rainfall**	**Annual Rainfall (mm)**	**Note**
Lima Kaum	0.47°S, 100.54 °E	1991 - 2020	**Tanah Datar**	450	1,560	January and December	1764	Planting season and bias correction
Sijunjung	0.60°S, 100.99 °E	1991 - 2020	**Sijunjung**	202	10,790	May and November	2038	Planting season and bias correction
Panti	0.28°N, 100.10 °E	1991 - 2020	**Pasaman**	248	2,999	April and November	2423	Planting season and bias correction
Luak	0.28°S, 100.68 °E	1991 - 2020	**Lima Puluh Kota**	750	1,406	April and November	1930	Planting season and bias correction
Class II West Sumatra	0.55°S, 100.30 °E	1991 - 2020	**Padang Pariaman**	137	-	April and November	4602	Bias correction
Minangkabau Class II	0.79°S, 100.29 °E	1991 - 2020	**Padang Pariaman**	5	-	March and November	3834	Bias correction

Table 2. The category of performance based on R and PBIAS category (Moriasi et al., 2015)

Coefficient of correlation (R)	Percent of BIAS (PBIAS)	Accuracy
0.80 - 1.00	PBIAS < ± 10	very good
0.60 - 0.79	± 10 < PBIAS <± 15	good
0.40 - 0.59	± 15 < PBIAS <± 25	moderate
0.20 - 0.39	PBIAS > ± 25	not satistified

2. MATERIAL AND METHODS

2.1 Study Area

The dry Agroclimate area of West Sumatra were selected as study sites, such as: Panti (Pasaman Regency), Lima Kaum, Luak, and Sijunjung. The annual rainfall of the area in range of 1764 – 2422 mm, indicating an equatorial type with two rainy seasons and one dry season. The characteristics of the four locations are available Table 1.

2.2 Datasets

Monthly Climate data (temperature, rainfall, and sunshine) were obtained from the West Sumatra Climatology Stations in Lima Kaum Tanah Datar Regency, Panti Pasaman regency, Luak, Lima Puluh Kota Regency, Sijunjung regency and TerraClimate data for 1991 - 2020. The TerraClimate data was accessed from https://app.climateengine.org/climateEngine. The climate data was used to calculate potential evapotranspiration (PET) and Potential Water Deficit (PWD).

2.3 TerraClimate Data Validation

Bias correction is We validated TerraClimate data with observation rainfall data for the same period. We evaluated based on statistical matrix, such as the Pearson correlation coefficient (R), mean absolute error (MAE), root mean square error (RMSE), and percent bias (PBIAS), which were calculated with the Equation 1 – 4:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - x_i| \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - x_i)^2} \quad (2)$$

$$PBIAS = 100 \times \frac{\sum_{i=1}^{n}(y_i - x_i)}{\sum_{i=1}^{n}x_i} \quad (3)$$

$$R = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{(n\sum x_i^2 - (\sum x_i)^2)(n\sum y_i^2 - (\sum y_i)^2)}} \quad (4)$$

2.4 Water Balance Model

We used a monthly Thornthwaite and Mather water balance model to determine the surplus or deficit of rice plant water requirements. The water balance is a combination of climatological data (rainfall and temperature) and crop coefficient data. The water balance is made for a specific purpose on the type of rice. Crop coefficient data contributed to determine water requirements for each stage of rice development.

Monthly crop evapotranspiration was calculated using approach of (Allen et al., 1998), as in Equation 5.

$$PET = kc \; x \; Eto \quad (5)$$

where PET is potential crop evapotranspiration (mm/day), ETo is reference evapotranspiration (mm/day), and Kc represents crop coefficient depending on development stage of rice.

The water balance was calculated based on book keeping method in Microsoft Excels (Thornthwaite and Mather, 1957), as follows :

1. The Field Capacity (FC) was estimated according to the soil type found in the study area. FC represents the maximum soil water content, and a value of 350 mm was assumed for the research site.
2. Calculation of the differences between P and PET. In this analysis PET was from Equation (5), which has been corrected by the length of the day and the number of days.
3. Accumulation of potential water loss (APWL) is calculated when the P-PET showed negative value, and it's accumulated on a monthly basis.
4. Soil water content (SWC) was calculated based on Equation 6 depending on APWL value. The SWC value of the first month when P-PET is positive was calculated by Equation 7.

$$SWC = FC \times k \times |APWL| \quad (6)$$

$$SWC = \text{last SWC} + (P - PET) \quad (7)$$

k = p0 + p1/FC
p0 = 1.000412351
p1 = 1.073807306

5. Change of Soil Water Contain (dSWC) was calculated on monthly basis as difference of SWC between monthly periods.
6. When monthly P > PET then actual evapotranspiration (ETa) is equal to PET. Otherwise, ETa value was calculated in Equation 8.

$$ET_a = P + |dSWC| \quad (8)$$

7. The deficit water condition is defined when ETa is

Table 3. Validation of terraclimate data with Class II West Sumatra Climate Station data.

Location	MAE (mm)	RMSE (mm)	PBIAS (%)		Correlation (r)	
			%	Category	Value	Category
Lima Kaum	84.84	104.83	-1.12	Very good	0.37	Poor
Sijunjung	81.17	123.40	-0.31	Very good	0.57	Moderate
Panti	166.93	191.44	-0.62	Very good	0.53	Moderate
Luak	106.69	128.23	-0.38	Very good	0.31	Poor
Staklim BMKG	122.34	161.53	0.12	Very good	0.62	Strong
Stamet BIM	90.83	125.07	0.05	Very good	0.67	Strong

bigger than PET. Surplus water condition is when rainfall is bigger than the PET value.

In this research we used water balance condition (surplus and deficit water) as reference to arrange the cropping pattern. The cropping pattern in each region is determined based on the average monthly rainfall pattern or based on the potential and supply pattern of the nearest water source. Other research applied P/PE ratio as a reference for determining the length of cropping pattern (Hirwa et al., 2022).

3. Results and discussion

3.1 TerraClimate Data Validation

Table 2 shows the range of MAE values between 81.17 mm (Sijunjung) to 166.93 mm (Panti). The average MAE of the six stations has a correlation of 0.45 (moderate) with the average rainfall at the research location. The RMSE value of rainfall is very good in Lima Kaum (104.83 mm) and Sijunjung (123.4 mm), and the correlation values are strong (0.62 and 0.67 in BMKG Kayu tanam and BIM).

3.2 The influence of strong IOD on rainfall in West Sumatra

West Sumatra is influenced by global sea surface temperature activity in Indian waters. Changes in sea surface temperature activity will affect the positive or negative anomaly period. Each period affects changes in rainfall patterns. In the IOD phase strong positive rainfall decreases to below normal, conversely in the negative IOD phase rainfall increases SWC to above normal (Kurniadi et al., 2021). Topography is also influencing towards the precipitation, and it is shown by its values whether on IOD negative or positive.

Positive IOD can affect rainfall at the research location with a reduction at different times, in Lima Kaum there was a decrease in rainfall when IOD was positive: from August and October 2015, April to June 2017, May – September 2019, November 2019. Sijunjung location rainfall decreased in August, September 2012, and January 2019. Panti experienced a decrease in rainfall in October 2015, June to December 2016, and May – August 2019. Luak location, Lima Puluh Kota Regency, rainfall decreased in August and October 2015, April and July 2017, and September to November 2019. The influence of positive/negative IOD based on data does not always consistently affect the nature of rain at the research location, there are differences in each location, This difference is caused by intraseasonal weather anamnesis, wind movement, the influence of slope, contour, and topography of the area. Positive IOD affects reducing rainfall in West Sumatra in August and October 2015 and May to August 2019. Positive IOD does not have a direct effect on all study locations. IOD more than +0.5 from September 2018 to November 2019 which reduced rainfall in Lima Kaum Batu Sangkar during that period with below normal characteristics in November – December 2018 and August – September 2019.

3.3 Characteristics of rainfall

Based on our analysis, the monthly rainfall > 200 mm observed in November to January and March to April. The peak rainfall occurred in November and April, while the low rainfall (<100 mm/month) was recorded for June to July.

3.3.1 Lima Kaum, Tanah Datar Regency

Lima Kaum falls under the dry category (E1) in the Oldeman Agroclimatic Zone. From November to April, there is a surplus period exceeding 50 mm, while a water deficit occurs from May to September (Figure 3a), with a strong correlation of 0.95 between rainfall and water balance. The surplus does not go beyond 100 mm/month. Thornthwaite and Mather developed a drought index based on the percentage ratio of water deficit to potential evapotranspiration (Chattopadhyay et al., 2020). The water requirement for rice in one season is 711 mm (Aryal, 2013), indicating a mild drought from May to September.

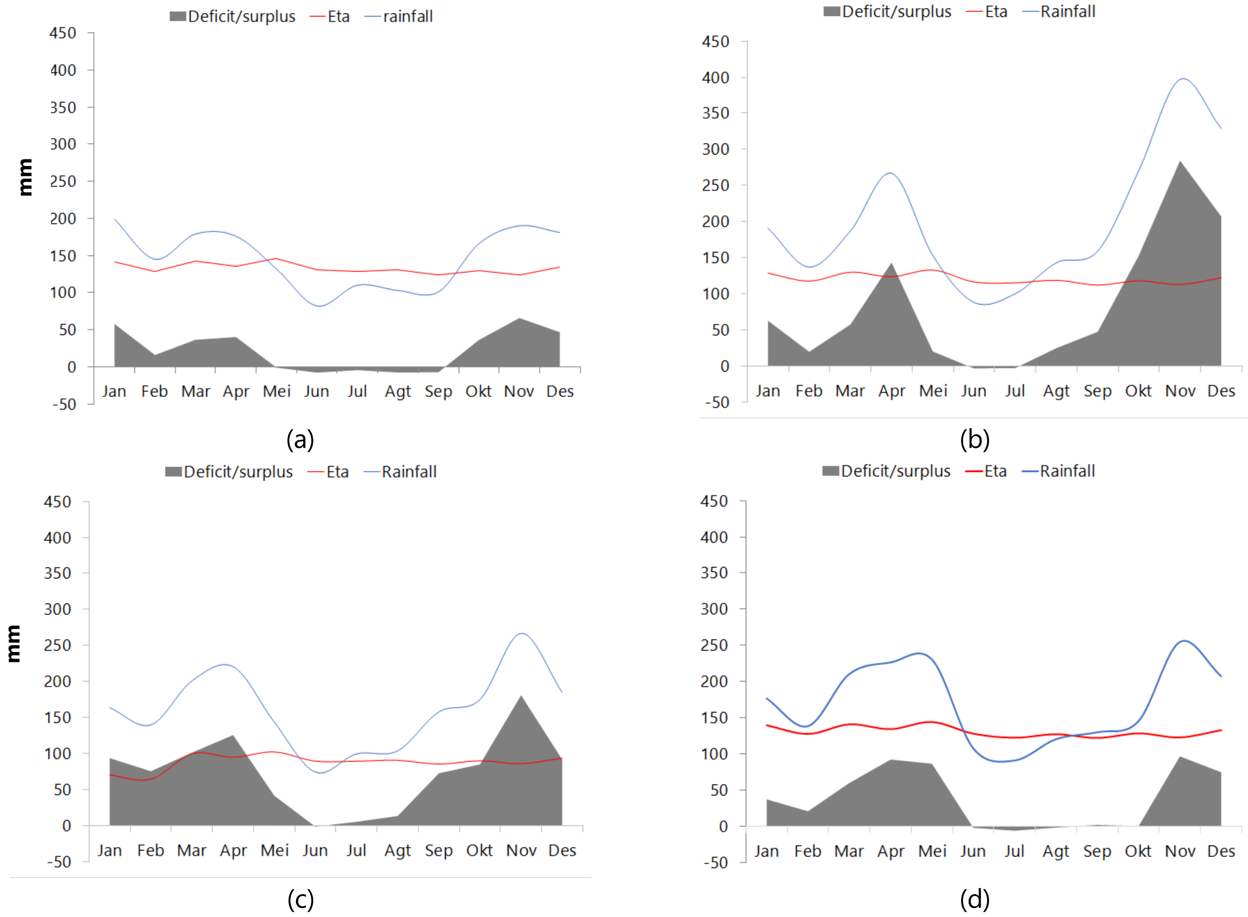


Figure 1. Graph of surplus or deficit of water balance (grey colour), actual evapotranspiration (Eta-red lines) and rainfall (blue lines) in Lima Kaum (a), Panti (b), Luak (c), and Sijunjung (d).

Actual evapotranspiration surpasses rainfall, leading to a deficit. Rainfed rice fields are unsuitable for rice cultivation during this period without an additional 172 mm of water, so farmers are advised to grow secondary crops like corn and beans. However, irrigated fields can still support one or two rice-growing cycles. Rainfed rice planting in October-November requires extra water if a reservoir is available. Even in surplus periods, irrigation should align with crop needs.

3.3.2 Panti, Pasaman Regency

Panti is categorized under the dry climate (D1) in the Oldeman Agroclimate Zone (Figure 3b). A surplus of over 50 mm occurs from October to January, while a deficit happens in June and July. The actual evapotranspiration exceeds rainfall, resulting in a deficit. Rainfall and water balance correlation is 0.99 (very high). Rainfed rice fields can support only one planting season per year, while the second season is more suitable for secondary crops. In irrigated fields, rice can be grown twice a year, but the second planting (March to June) requires an additional 117 mm of irrigation. A deficit occurs in June and July, categorized as mild drought.

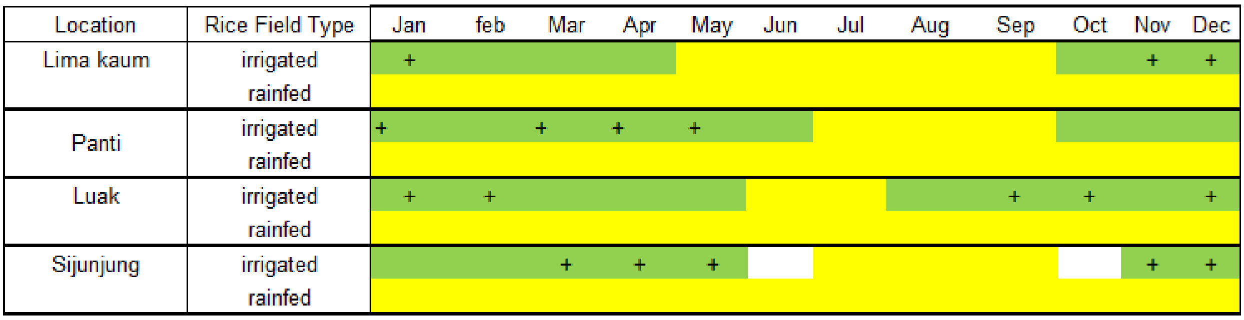
3.3.3 Luak, Lima Puluh Kota regency

Luak falls under the dry climate category (E2) in the Oldeman Agroclimate Zone (Figure 3c). A surplus exceeding 50 mm occurs from September to April, while a deficit is seen in June. The actual evapotranspiration surpasses rainfall, leading to a deficit. The correlation between rainfall and water balance is 0.97 (very high). The surplus period exceeds 100 mm/month from November to April, but available water declines afterward, becoming insufficient for rice growth. Consequently, rainfed rice fields can accommodate one planting season per year. If the rainy season starts in October, farmers may be able to plant twice, extending until May. A climate field school experiment by Class II West Sumatra Climate Station (2022) and BPTPH in simple irrigated rice fields (July-October 2022) reported a 30% increase in crop yield.

3.3.4 Sijunjung, Sijunjung Regency

Sijunjung is classified as a humid climate (D1) in the Oldeman Agroclimate Zone (Figure 3d). Surplus periods occur from April to May and November to December, while a deficit is observed from June to October, with a mild drought index. Actual evapotranspiration exceeds rainfall, and the rainfall water balance asses 100 mm/month. Rice planting from September to December requires an additional 228 mm of irrigation. Depending on irrigation availability, one or two planting seasons are possible. Rice cultivation lasts 15-

Table 4. West Sumatra Crop Season for rainfed and irrigated rice fields in dry agroclimate areas



Description:

Paddy

Secondary Crops

irrigation +

No crops

20 days with a water need of 150-250 mm (Matloob et al., 2022; Surmaini and Syahbudin, 2016). The timing of planting should also account for the time needed for soil saturation. In June and October, it is best to leave the rice fields fallow since this period experiences a water deficit and remains in the dry season. As a result, it is not advisable for initial rice planting,though it can still be used for growing secondary crops.

4. Discussion

A comparison of TerraClimate's actual evapotranspiration (ET) with observational data reveals a strong to very strong correlation at two locations: Luak, Lima Kaum, and a weak correlation at Sijunjung and Panti. This variation indicates differences in the accuracy of TerraClimate data across different regions ((Solaimani and Ahmadi, 2024) The reference evapotranspiration data from TerraClimate is estimated using the Penman-Monteith-FAO method, which tends to be more consistent compared to the Thornthwaite method. As a result, the accuracy of the data and the lack of evapotranspiration observations make TerraClimate data a valuable resource for studies and research.

In regions without observation stations, the density of data remains insufficient, leading to challenges in obtaining appropriately distributed data. (Filgueiras et al., 2022) evaluated TerraClimate data in Brazil between 2000 and 2017 and found reasonable similarities in reference data for temperature, rainfall, and evapotranspiration, making it a reliable alternative to ground-measured climate data. Additionally, studies by (Araghi et al., 2023; Hamarash et al., 2022) highlight a strong correlation between station based evapotranspiration and satellite derived data. This is also in line with research (Wiwoho and Astuti, 2022) which showed that TerraClimate rainfall data has strong accuracy and correlation in tropical country, especially in Brantas watershed, Indonesia.

However, there is still a lack of actual climate data for each location due to the limitations of the tools that can use a combination of terraclimate data and actual field data to obtain accurate data. Sufficient real-time climate data can enhance the accuracy of water balance calculations in the field, ensuring the optimal planting pattern is achieved. Future studies should aim to test these methods over wider areas and consider specific commodities to enhance the understanding of their accuracy. Conducting tests with more precise measurements of the rice plant coefficient, soil types, soil moisture levels, and consecutive dry days, while also considering specific crops, can improve the accuracy of determining planting seasons in dry climates and rainfed rice fields. Farmers can use these insights to plan the planting season and schedule irrigation accordingly.

5. Conclusion

In the locations of rainfed rice fields that experience changes in planting seasons, there are different deficit periods. The longest deficit period in Lima Kaum, Tanah Datar Regency during May to September and the shortest in June in Luak, Lima Puluh Kota Regency. The surplus period also differs in each region, the shortest surplus period has the potential to meet the availability of rice water in Lima Kaum in February, the longest period in Panti, Pasaman Regency from October to December and April. Rice planting is not possible throughout the year. The planting season in rainfed rice fields has the potential to be carried out once, for two planting seasons it must be with the addition of irrigation water and/or adjustment of transitional commodities to other food crops. Based on the findings of this study, it is advised that stakeholders in water resources, agriculture, and environmental planning make decisions that enable adaptation to both present and future climate conditions to minimize potential damage.

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