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Water balance optimization for strategic planting patterns and calendars in paddy (*Oryza sativa* L.) cultivation in rainfed regions

Optimasi neraca air untuk strategi pola dan kalender penanaman pada budidaya padi (*Oryza sativa* L.) di daerah tadah hujan

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ABSTRACT

Paddy (*Oryza sativa* L.) is a staple food crop in Indonesia that requires more water compared to other annual crops. Cultivating paddy in rainfed areas necessitates effective water management to prevent crop failure, making it essential to calculate water balance, planting patterns, and planting calendars. This study aims to analyze the water balance in relation to planting patterns and calendars based on water availability in the field. The research was conducted in Cukilan Village, Semarang Regency, Indonesia. A descriptive quantitative method using Cropwat 8.0 was employed to determine water balance, planting patterns, and planting calendars. The results indicate that from November to April, there is a water surplus, while from May to October, there is a water deficit. Planting can be conducted once per growing season with two possible periods: November-March or December-April. During Period I (November-March), the water requirement is 640.7 mm with effective rainfall of 1031.2 mm. In Period II (December-April), the water requirement is 638 mm with effective rainfall of 935.7 mm. Planting should begin in November or December, with harvest in March or April. From May to October, the land remains fallow due to insufficient water availability. These findings are valuable for enhancing the effectiveness of paddy cultivation in rainfed areas, assisting farmers with planting planning, and minimizing the risk of crop failure due to water scarcity.

ABSTRAK

Tanaman padi (*Oryza sativa* L.) merupakan tanaman pangan pokok bagi masyarakat Indonesia yang membutuhkan air lebih banyak dibandingkan tanaman semusim lainnya. Budidaya padi pada lahan tadah hujan memerlukan manajemen air yang baik untuk menghindari kegagalan, sehingga perhitungan neraca air, pola tanam, dan kalender tanam sangat diperlukan. Penelitian ini bertujuan untuk menganalisis neraca air terhadap pola tanam dan kalender tanam padi berdasarkan ketersediaan air di lahan. Penelitian dilakukan di Desa Cukilan, Kabupaten Semarang, Indonesia. Metode deskriptif kuantitatif dengan Cropwat 8.0 digunakan untuk menentukan neraca air, pola tanam, dan kalender tanam. Hasil penelitian menunjukkan bahwa dari bulan November hingga April terjadi surplus air, sedangkan dari Mei hingga Oktober terjadi defisit air. Penanaman dapat dilakukan dengan satu kali musim tanam dengan dua periode pilihan, yaitu periode November-Maret atau periode Desember-April. Pada periode I (November-Maret), kebutuhan air sebesar 640.7 mm dengan curah hujan efektif 1031.2 mm. Pada periode II (Desember-April), kebutuhan air sebesar 638 mm dengan curah hujan efektif 935.7 mm. Penanaman dimulai pada bulan November atau Desember dan panen pada bulan Maret atau April. Dari Mei hingga Oktober, lahan tidak ditanami karena ketersediaan air tidak mencukupi. Temuan ini bermanfaat untuk meningkatkan efektivitas budidaya padi di lahan tadah hujan, membantu petani dalam perencanaan tanam, dan meminimalkan risiko kegagalan panen akibat kekurangan air.

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INTRODUCTION

Paddy (*Oryza sativa* L.) is a staple food crop for the Indonesian population, requiring higher water input compared to other seasonal crops such as pulses. Therefore, paddy cultivation in rainfed areas is prone to drought, which can lead to reduced production yields (Hariyanti et al., 2020). In rainfed areas, rainfall is the sole water source available to meet the water requirements of the crops. Hence, rainfall is a crucial climatic element that significantly influences the growth and yield of paddy (Kadiyala et al., 2015). Throughout its growth cycle, paddy requires a high-water availability, although the amount of water needs to be reduced at certain growth stages (Karim & Aliyah, 2019; Aryal, 2013). Overall, the water requirement for paddy throughout its life cycle is higher compared to other seasonal crops such as pulses or horticultural crops (Vijayakumar et al., 2022).

Water availability has a significant impact on the growth and development of paddy plants. Therefore, effective and efficient water management is essential to ensure optimal plant growth (Rahmadani et al., 2020). In rainfed areas, one of the strategies that can be implemented is the determination of cropping patterns and planting calendars based on soil water balance. A cropping pattern refers to the arrangement of crops in a specific sequence and layout over a given period on agricultural land (Suryanto, 2019). The development of cropping patterns can reduce the risk of crop failure (Hilman et al., 2019). Cropping pattern planning is carried out to align with rainfall distribution and the minimum water requirements of the crops to be cultivated (Tentua et al., 2022). Cropping patterns provide a framework for determining when crops can efficiently utilize available water.

A planting calendar is a schedule for planting specific crops throughout the year on a given land area with a predetermined cropping pattern, including periods for soil preparation, planting, and harvesting (FAO, 1997). The aim of determining cropping patterns and planting calendars is to enhance agricultural yields by minimizing the risk of crop failure due to water shortages. Accurate cropping patterns and planting calendars can provide solutions to nutrient loss and water deficiency in crops (Karim & Aliyah, 2019). These patterns and calendars are adjusted based on water availability using a water balance approach. Water balance represents the equilibrium between the amount of water entering and leaving a land area over a specific period (Widiyono, 2016; Paski et al., 2017). Through water balance analysis, the water availability status in a region can be determined, whether it is in surplus or deficit (Mentang et al., 2017). Surplus and deficit data can be used for planning water usage, determining the optimal planting time, and appropriate planting patterns. Water balance analysis provides information on soil water availability, evapotranspiration, and periods of water surplus and deficit (Musyadik et al., 2014; Lu et al., 2024).

This research builds upon relevant previous studies, which provide a strong foundation for deeper analysis. For instance, a study conducted in Bengkulu City, Indonesia, using the Thornthwaite and Mather method, showed that the rainfall amount in the city is ideal for paddy growth (Paski et al., 2017). The study found that paddy could be planted throughout the year with the first planting schedule from November to February, the second from March to June, and the third from July to October. However, the study also concluded that soil water availability conditions in Bengkulu City are not suitable for maize cultivation, suggesting the need to try other pulse crops.

Another study conducted in Kampar Regency, Indonesia, also using the Thornthwaite and Mather method, aimed to determine the planting time for upland paddy (Pratiwi et al., 2022). The results indicated that upland paddy planting in Homogeneous Land Units (HLU) 1 to 7 using the inpago variety can be done in January, May, and September. Meanwhile, in HLU 8, inpago variety planting is done in January and September. For local varieties, planting in HLU 1 to 7 is done in February and September, while in HLU 8 it is done in March and September. As an alternative, inpago variety can be planted in February and local varieties in September. Additionally, a study in Lewa District, East Sumba Regency, Indonesia, using the NRCS Java Newhall Simulation Model (jNSM), determined water balance-based planting patterns for paddy and maize (Killa et al., 2018). The study results showed that the planting pattern was designed based on water availability and divided into two regions. Region I can only be planted once a year during the rainy season (December-

April) with either paddy or maize. Region II can be maximized with two planting cycles a year with the planting pattern of maize-paddy or maize-maize. These studies have illustrated the importance of good water management and planting pattern planning to achieve success in paddy and other crop cultivation.

While previous studies have provided valuable insights into the importance of water management and planting patterns for paddy cultivation, they often rely on generalized methods that may not account for specific local conditions. Moreover, there is a lack of detailed analysis on how water balance specifically influences the planting calendars and patterns in different rainfed regions using advanced tools such as Cropwat 8.0. Previous research has not thoroughly examined the long-term sustainability and adaptability of these patterns under varying climatic conditions.

This research aims to fill these gaps by analyzing water availability under surplus or deficit conditions and creating planting scenarios throughout the paddy life cycle using the Cropwat 8.0 application developed by the Food and Agriculture Organization (FAO) based on the Penman-Monteith model. This model is known for its accuracy in determining water requirements for crop growth, considering factors such as soil type, climatic conditions, and crop data. Additionally, supporting field data parameters from soil characteristic analysis, including soil texture, organic matter, soil permeability, and porosity, provide an accurate representation of soil water storage capacity and downward water movement, thereby accurately predicting water availability for paddy crops(Hanafiah, 2012). Therefore, the objective of this study is to analyze the land water balance conditions to determine paddy planting patterns and calendars based on water availability for paddy crops.

MATERIALS & METHODS

This study was conducted in Cukilan Village, Suruh District, Semarang Regency, Indonesia (Latitude 7° 20' 29.137" S and Longitude 110° 35' 28.012" E), as shown in Figure 1. Soil analysis was performed at the Soil Laboratory of the Faculty of Agriculture and Business, Satya Wacana Christian University, Salatiga.

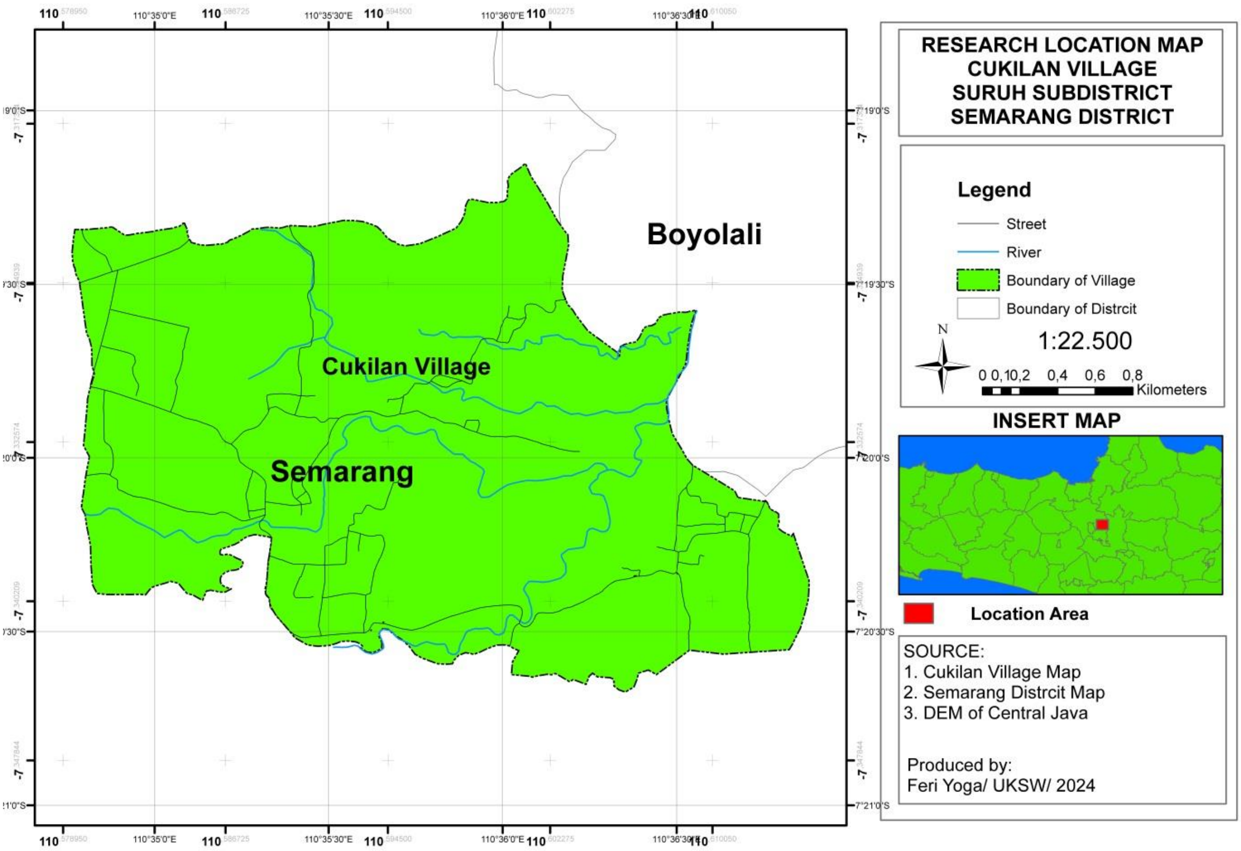


Figure 1. Research location map

Materials used in this study included calgon 40 g/L (Merck Millipore, USA) as a binding agent for soil texture analysis. Concentrated sulfuric acid (H_2SO_4) (Merck, Germany) and $K_2Cr_2O_7$ 1N (Merck, Germany) were used for organic matter analysis. Cropwat 8.0 (FAO, USA) was employed for water balance calculations and determining crop water requirements, while Microsoft Excel 10 (Microsoft Corporation, USA) was utilized for data analysis and processing. ArcGIS 10.8 (Esri, USA) was used for mapping and spatial analysis of the research data. In addition to these materials, standard laboratory equipment for soil analysis and a computer with specifications supporting the use of Cropwat 8.0, Microsoft Excel 10, and ArcGIS 10.8 software were also used in this study.

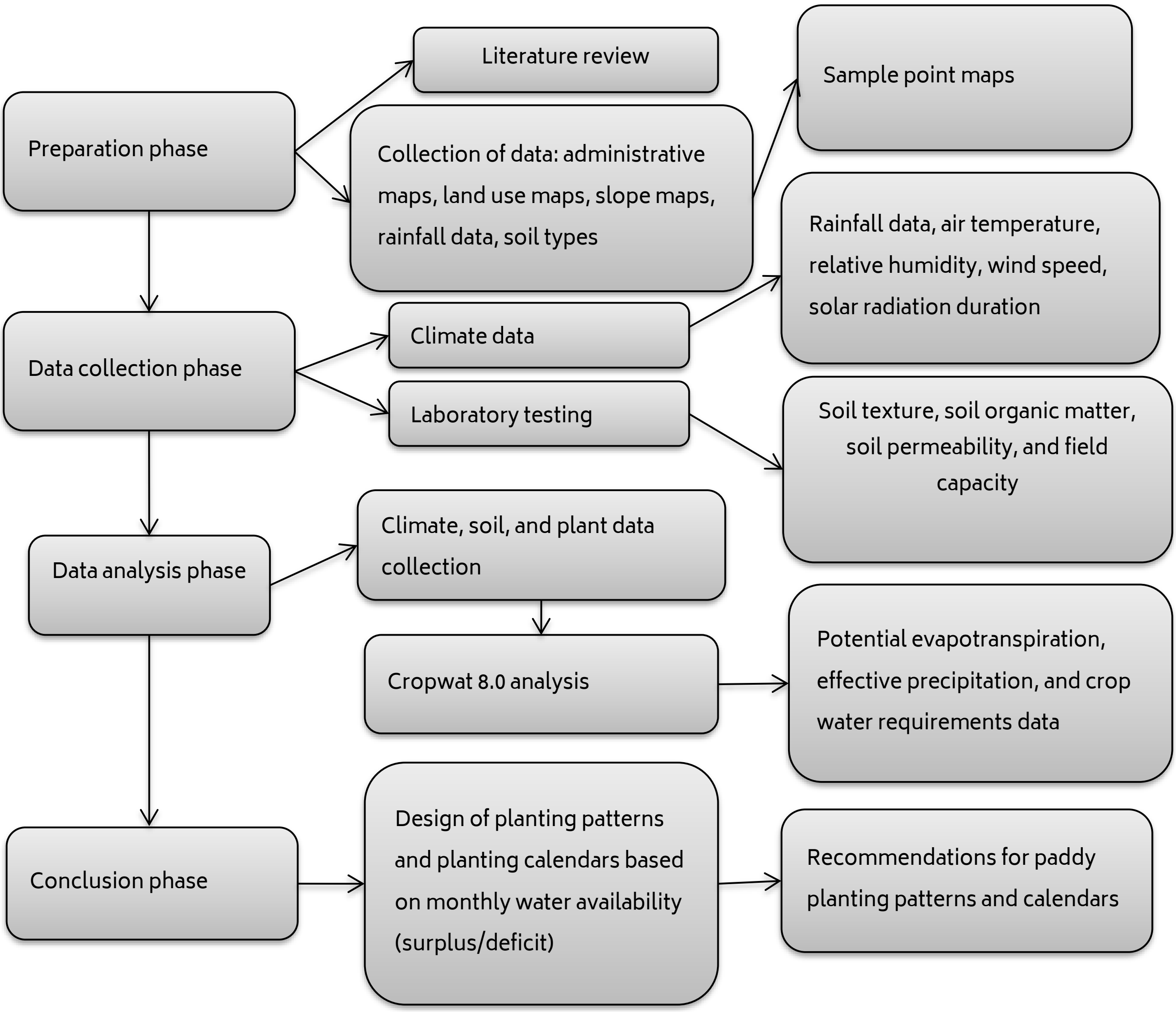


Figure 2. Research stages in this study

This study employed a descriptive quantitative method, which is a research approach designed to objectively describe and analyze a situation using numerical data, as followed previous study (Arikunto, 2010). This method is particularly suitable for environmental analysis, allowing for detailed examination and interpretation of complex data sets. The approach includes data collection, data interpretation, and presentation and analysis of the results obtained. Data collection encompassed both primary and secondary data. Primary data were directly analyzed from soil samples, which included parameters such as soil texture, organic matter, soil permeability, soil porosity, and field capacity water content. The sampling technique for soil samples was conducted using a systematic random method with a detailed accuracy level, yielding a total of 40 soil samples. This number of samples ensures statistical relevance and robustness for the analysis (Taherdoost, 2018).

Secondary data included administrative maps, land use maps, soil type maps, slope maps, and climate data. The climate data, which covered rainfall, air temperature, wind speed, sunshine duration, and relative humidity, were obtained from the NASA website (https://power.larc.nasa.gov) based on the last 10 years of data from 2012 to 2021. NASA data were chosen due to their credibility and accessibility, providing reliable and comprehensive climatic information (Fadla, 2022). The integration of primary and secondary data allows for a comprehensive analysis of water balance and its impact on paddy cultivation. The research stages, including data collection, analysis, and interpretation, are illustrated in Figure 2.

Soil texture was determined using the Bouyoucos method and expressed as a percentage (Beretta et al., 2014). Organic matter content was measured using the carbon content method with a spectrophotometer, also expressed as a percentage (Zulfa & Bowo, 2023). Soil permeability was assessed using Darcy's law for water flow and reported in centimeters per hour (cm/h) (Minangkabau et al., 2022). Soil porosity was calculated based on soil bulk density with a grain density of 2.65 g/cm3 and expressed as a percentage (Minangkabau et al., 2022). Field capacity, the soil water content available for plants, was measured using the Alhricks method and expressed as a percentage (Haridjaja et al., 2013).

Climate data including temperature, relative humidity, solar radiation, and wind speed were analyzed to calculate potential evapotranspiration using the Cropwat 8.0 application developed by FAO (1997), based on the Penman-Monteith method. The formula for potential evapotranspiration (ETo) using Penman-Monteith is as follows:

$$ET_0 = \frac{0{,}48\Delta(\mathrm{Rn}-\mathrm{G})+\gamma\frac{900}{(T+273)}\times \mathrm{U2}(e_s-e_a)}{\Delta+\gamma(1+0.34\times U_2)} \quad (1)$$

where:

ET_0 = reference crop evapotranspiration (mm/day)
Rn = net radiation at the crop surface (MJ/m2/day)
G = soil heat flux density (MJ/m2/day)
T = mean daily air temperature at 2 meters height (°C)
U2 = wind speed at 2 meters height (m/s)
es = saturation vapor pressure (kPa)
ea = actual vapor pressure (kPa)
Δ = slope of the vapor pressure curve (kPa/°C)
γ = psychrometric constant (kPa/°C)

Effective rainfall is defined as the portion of rainfall that can be directly utilized by plants to meet their water needs during the growing season (Hidayat & Empung, 2016). Effective rainfall was calculated based on monthly rainfall data using the empirical formula according to FAO (1997):

$P_{eff} = 0.6 \times (P - 24)$, untuk Ptotal > 70 mm (2)
$P_{eff} = 0.6 \times (P - 10)$, untuk Ptotal < 70 mm (3)

where:

P_{eff} = effective rainfall (mm/month)
P = total monthly rainfall (mm/month)

The condition of water surplus or deficit was determined by subtracting potential evapotranspiration from rainfall based on the method of Fathnur et al., (2021). The planting patterns and calendars for paddy were developed based on planting scenarios that consider months with sufficient water surplus to meet the water requirements of paddy throughout its growth cycle (Pratiwi et al., 2022;Handika et al., 2015). Months with surplus water, as identified by the Cropwat 8.0 application, were used to inform the design of planting patterns and calendars for paddy.

RESULTS & DISCUSSIONS

Soil and climate characteristics in the study area

The characteristics of the soil and climate in the study area were crucial for determining the suitability for paddy cultivation. Based on the analyzed primary data (see Table 1), the soil in this region had a loamy texture, with a clay fraction of 13.03%, a sand fraction of 34.45%, and a silt fraction of 52.53%. This texture indicated good water retention capacity, efficient water and air movement within the soil, and adequate aeration for root development. Additionally, soil organic matter was measured at 7.13% using carbon content analysis (spectrophotometer). Soil permeability, measured using Darcy's law, was 3.98 cm/hour. Soil porosity, determined from bulk density and particle density (2.65 g/cm3), was 60.91%. The field capacity, measured using the Alhricks method, was 346 mm/m. These parameters suggested that the soil in the study area had properties that supported optimal paddy growth by providing good aeration and effective drainage(Hanafiah, 2012;Nangaro et al., 2021).

Regarding climate, the average air temperature in the study area was 25°C, which was suitable for paddy growth (Paski et al., 2017). The relative humidity was 83%, which was optimal for paddy cultivation (Sridevi & Chellamuthu, 2015). The solar radiation duration was 7.9 hours per day, which was considered long but still supported good paddy production (Gusira et al., 2020). The wind speed in the area was 1.7 m/s, which was moderate. These climatic conditions provided strong support for paddy cultivation and contributed to favorable harvest outcomes.

Table 1. Soil and climate characteristics

Parameter	Method/Source	Unit	Result
Clay fraction	Bouyoucos	(%)	13.03
Sand fraction	Bouyoucos	(%)	34.45
Silt fraction	Bouyoucos	(%)	52.53
Tekstur	Bouyoucos		Loamy
Organic matter	Spectrophotometer	(%)	7.13
Field capacity	Alhricks	(mm/m)	346
Permeability	Darcy's Law	(cm/hour)	3.98
Soil porosity	Bulk & particle density	(%)	60.91
Air temperature	NASA Power	(°C)	25
Relative humidity	NASA Power	(%)	83
Wind speed	NASA Power	(m/s)	1.7
Solar radiation duration	NASA Power	(hours/day)	7.9

Table 2. Effective precipitation

Precipitation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CH (mm/ month)	368.6	397.1	193.5	200.3	128.2	97.4	59.9	39.9	92.7	121.9	201	283
CHE (mm/month)	270.9	293.7	130.8	136.2	78.6	53.9	25.9	13.9	50.2	73.5	136.8	202.4

Note: CH = precipitation (mm/month); CHE = effective precipitation (mm/month)

Effective precipitation

According to Table 2, the highest monthly precipitation occurred in February, amounting to 397.1 mm, while the lowest was in August with only 39.9 mm. The annual effective precipitation totaled 1466.8 mm. The highest monthly effective precipitation was also observed in February, at 293.7 mm, whereas the lowest was in August, at 13.9 mm. These precipitation data are suitable for supporting paddy growth. As stated by Paski et al. (2017), paddy requires approximately 200 mm of rainfall per month over a four-month period, with an ideal annual rainfall ranging from 1500 to 2000 mm.

Potential evapotranspiration

Potential evapotranspiration exhibited monthly fluctuations, as illustrated in Figure 3. The average monthly potential evapotranspiration was 134.3 mm. The peak evapotranspiration was recorded in September at 170.46 mm per month, while the lowest value occurred in February at 108.4 mm per month. The potential evapotranspiration values are influenced by climatic factors such as air temperature, wind speed, sunshine duration, and humidity. Potential evapotranspiration positively correlates with air temperature, wind speed, and sunshine duration. As potential evapotranspiration increases, air temperature, wind speed, and sunshine duration tend to rise as well. Conversely, potential evapotranspiration negatively correlates with relative humidity. When potential evapotranspiration increases, relative humidity tends to decrease (Wilnaldo et al., 2020).

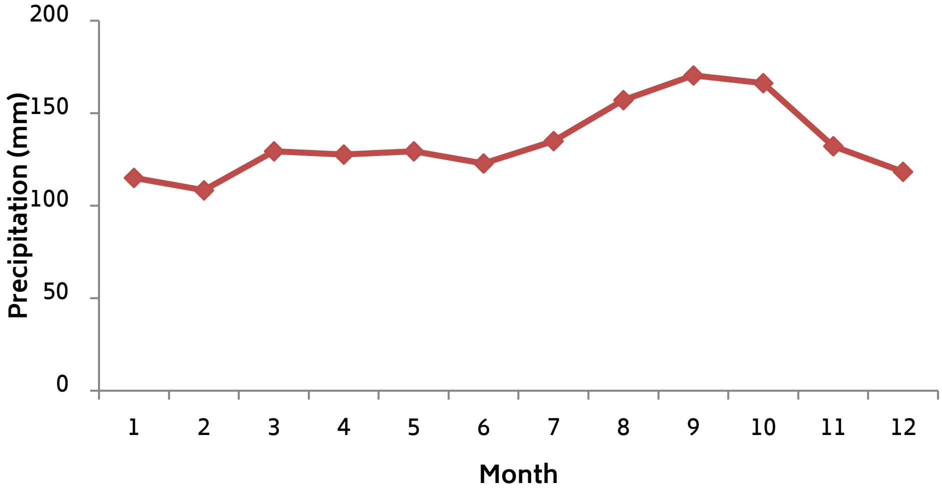


Figure 3. Monthly potential evapotranspiration

Table 3. Soil water balance in Cukilan Village

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CH (mm/month)	368.6	397.1	193.5	200.3	128.2	97.4	59.9	39.9	92.7	121.9	201	283
ETp (mm/month)	115.1	108.4	129.4	127.7	129.4	122.9	135	157.1	170.5	166.3	132.16	118.32
Soil water availability	253.5	288.7	64.1	72.63	-1.2	-25.5	-75.1	-117	-77.75	-44.35	68.84	164.68
Soil water condition	S	S	S	S	D	D	D	D	D	D	S	S

Note: S = Surplus, D = Deficit, CH = Rainfall (mm/month), ETp = Potential Evapotranspiration (mm/month)

Soil water surplus-deficit

The water balance represents the equilibrium between the amount of water entering and leaving a land area over a specific period (Widiyono, 2016; Paski et al., 2017). The basic principle of the water balance depicts the balance between the amount of incoming, outgoing, and available water in an area. Understanding the conditions of water surplus and deficit can aid in comprehending water resource potential and managing its utilization optimally. When rainfall exceeds potential evapotranspiration (P > ETp), groundwater increases, indicating a sufficient water supply, and the land may experience water surplus (S). Conversely, when rainfall is less than potential evapotranspiration (P < ETp), soil water content decreases, potentially leading to a water deficit (D)(Fathnur et al., 2021).

According to Table 3, the months of water surplus occur from November to April, while the water deficit months range from May to October. Factors such as climate, soil characteristics, and soil type play roles in determining the conditions of water surplus and deficit in the study area. Climate is the primary determinant in the land water balance (Paski et al., 2017; Tufaila et al., 2017)

Water requirements for paddy

Paddy is a crop that requires significantly more water compared to other crops. Mardawilis and Ritonga (2016) state that to maintain high productivity levels, rainfall during the vegetative phase of paddy plants needs to be higher than during the generative phase, with water requirements ranging between 200 and 372 mm per month. According to the Cropwat 8.0 application, paddy cultivation consists of five phases: land preparation or nursery (30 days), initial (20 days), development (30 days), mid-season (40 days), and late (30 days). Planting paddy during months with water surplus ensures sufficient water availability from planting to harvest, preventing water shortages during the paddy growth cycle (Pratiwi et al., 2022).

Table 4. Scenario I: Paddy planting period from November to March

Month	**November**			**December**			**January**			**February**			**March**		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Phase		Nurs/LPr		Init		Deve				Mid				Late	
Kc		1.08		1.1		1.12				1.14				1.07	
Etc(mm/month)		119.7		86.1		88.2				214				132.7	
CHE (mm/month)		137		127.5		159.1				480.3				127.3	
Condition		Surplus		Surplus		Surplus				Surplus				Surplus	

Note:
- Kc = Crop coefficient
- Etc = Crop evapotranspiration
- CHE = Effective rainfall
- LPr = Land preparation (nursery phase)
- Nurs = Nursery (seedling phase)
- Init = Initial (early phase)
- Deve = Development (flowering phase)
- Mid = Mid-season (fruiting phase)
- Late = Late (maturation phase)

Tables 4 and 5 indicate that paddy water requirements can be met from November and December through March and April. In Scenario I, total crop evapotranspiration is 640.7 mm, and total effective rainfall is 1031.1 mm. In Scenario II, total crop evapotranspiration is 638.3 mm, and total effective rainfall is 935.7 mm. Each growth phase of paddy has different water requirements, with the highest during the mid-season phase (214 mm in Scenario I and 227.5 mm in Scenario II) and the lowest during the initial phase (86.1 mm in Scenario I and 84 mm in Scenario II). The mid-season or generative phase, marked by panicle formation and growth, requires the most water. The initial or vegetative phase focuses on plant development from seedlings and the increase of tillers until the initial formation of panicles on the main stem. This aligns with research by Fuadi et al., (2016), which states that the type and growth stage of paddy affect its water consumption needs. Water demand increases with plant growth, peaking during panicle formation on the main stem, then decreasing as the grains mature (Sagita et al., 2020). When rainfall is insufficient to meet paddy water needs, supplementary water sources, such as irrigation, are necessary. Pratiwi et al. (2022) explain that adequate water is crucial in paddy cultivation to ensure optimal plant growth.

Table 5. Scenario II: Paddy planting period from December to April

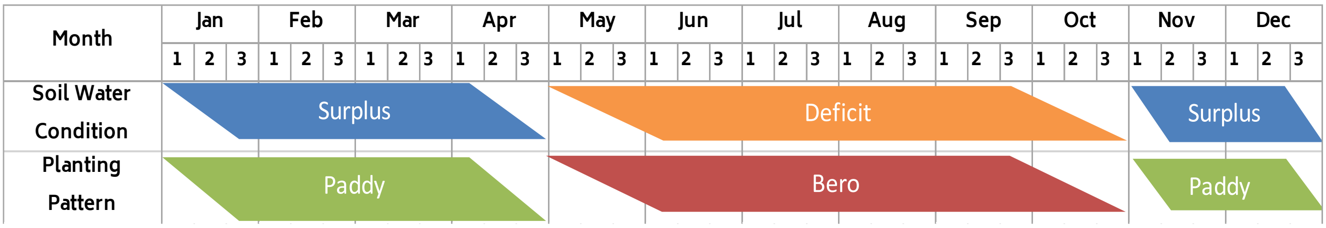
Month	December			January			February			March			April		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Phase		Nurs/LPr		Init		Deve				Mid				Late	
Kc		1.08		1.1		1.11				1.14				1.07	
Etc(mm/month)		104.4		82		88.8				227.5				135.6	
CHE (mm/month)		196.5		84.1		195.5				323.3				136.2	
Condition		Surplus		Surplus		Surplus				Surplus				Surplus	

Note:
- Kc = Crop coefficient
- Etc = Crop evapotranspiration
- CHE = Effective rainfall
- LPr = Land preparation (nursery phase)
- Nurs = Nursery (seedling phase)
- Init = Initial (early phase)
- Deve = Development (flowering phase)
- Mid = Mid-season (fruiting phase)
- Late = Late (maturation phase)

Design of planting patterns and calendars

A planting pattern is an agricultural effort to arrange the sequence of crops and/or the layout of crops over a certain period. The planting pattern determines the productivity of the land. As stated by Mahlayeye et al., (2022), a planting pattern is defined as the sequence and spatial arrangement of annual crops on a piece of land, where the planting pattern determines land productivity by regulating the intensity of land use.

Table 6. Design of planting patterns and calendars



Note:
Surplus = Groundwater condition having excess water for paddy cultivation
Deficit = Groundwater conditions lacking water for paddy cultivation
Paddy = Land suitable for paddy cultivation
Bero = Land not suitable for paddy cultivation

A planting calendar is the schedule for planting specific crops throughout the year in a given area, including periods of soil preparation, planting, and harvesting (FAO, 1997). It is a chronological representation of the phenological stages of plants in one growth cycle, showing when and how many times crops will be planted in a year (Mishra et al., 2021; Zhao et al., 2023). One determining factor of the planting calendar is the availability of water. Water availability is crucial for the continuity of the plant growth cycle. In paddy cultivation, the planting calendar serves as a tool for planning and managing activities related to the planting model, from seed preparation, planting, to harvesting (More et al., 2016). Adequate water availability from the initial planting phase to harvest reduces the risk of crop failure due to water shortages. Sufficient water helps the processes of photosynthesis and plant metabolism to function well, thus maximizing production yields. When soil moisture levels are low, plants cannot utilize the available water, leading to drought and wilting. Water shortages during the vegetative or generative stages can disrupt growth, reduce photosynthesis levels, and hinder the distribution of assimilates, ultimately lowering plant productivity (Sirait et al., 2020).

Based on the results of the planting pattern and calendar scenarios in the study area, considering the water balance conditions (water deficit-surplus per decade) and the water requirements for paddy ranging between 200-372 mm/month (Mardawilis & Ritonga, 2016), the planting pattern and calendar design were determined (see Table 6). The proposed pattern was paddy-fallow or a single planting per year, with planting scheduled from November to March and from December to April. Planting activities started with land preparation and seedling in November or December. Initial planting began in December or January, with harvesting in March or April. From May to October, the dry season made planting unfeasible due to insufficient water availability for paddy cultivation. This aligned with Killa et al. (2018), who found that the water surplus period was from November to April, and the water deficit period was from May to October, allowing for a single annual paddy planting. According to Fazhari et al., (2023), farmers with additional capital could install groundwater pumps to extend the paddy growing season during deficit months, as paddy required adequate water throughout its growth phases, and production declined when paddy experienced water deficits (Handika et al., 2015).

CONCLUSION

This study develops a planting pattern and calendar for paddy based on groundwater availability and crop water requirements. The analysis reveals that the annual effective rainfall is 1466.8 mm, with surplus water months from November to April and deficit months from May to October. Monthly potential evapotranspiration ranges from 108.4 mm to 170.46 mm, influenced by air temperature, wind speed, solar radiation, and relative humidity. An optimal paddy planting calendar is designed for the period from November to March or December to April, with planting starting in November or December and harvesting in March or April. This timing avoids the dry season between May and October, when water availability is insufficient. The study also suggests the use of groundwater pumps to extend the planting season if resources permit. These findings underscore the importance of careful water management planning to enhance paddy productivity and mitigate the risk of crop failure.

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