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Research Article

The Optimization of Cropping Pattern Based on Land Water Balance Analysis and Its Spatial Distribution in Rambipuji District, Jember

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Abstract

Optimizing cropping patterns under monsoon climates requires accurate information on soil water availability and its spatial variability. This study aimed to optimize cropping patterns and determine the optimal planting onset based on land-water balance analysis using the Thornthwaite-Mather water balance method and its spatial distribution in Rambipuji District, Jember Regency, Indonesia. Monthly land water balance was analyzed using the Thornthwaite–Mather method based on ten-year climatological data (2015–2024), including rainfall and reference evapotranspiration, and soil water holding capacity measurements across five land mapping units (LUMs) differentiated by slope, soil subgroup, and land use. Planting onset was determined using scientific criteria where soil moisture reached water holding capacity, and the effective rainfall to crop evapotranspiration was ≥ 0.75. The results showed a distinct monsoonal pattern, with water surpluses occurring from November to April and pronounced deficits from May to October. Soil texture significantly influenced water holding capacity, resulting in variations in the duration and intensity of water deficits among LUMs. Based on these conditions, LUM 1, 2, and 5 were recommended for planting in December, while LUM 3 and 4 were more suitable for January for the paddy crop. The optimal cropping pattern consisted of paddy cultivation in the first planting season followed by secondary crops in the second and third seasons, reflecting adaptive water-use strategies under declining rainfall. These findings demonstrate that integrating land-water balance analysis with spatial land characteristics provides a reliable basis for precision-oriented cropping calendar planning, supporting sustainable agricultural management.

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1. Introduction

The land water balance is the equilibrium between incoming water through precipitation (rain) and outgoing water through evapotranspiration on a plot of land (Proutsos et al., 2025; Sun et al., 2023).

This balance can illustrate the dynamics of water presence within the soil during plant growth periods, which may be used to estimate the amount of water required by crops during their growth and development until the production phase. Thornthwaite and Mather, in 1975, developed a land water balance model considering climatic equilibrium, namely precipitation (rain) and evapotranspiration.

The Land water balance analysis provides key information on water availability and surplus-deficit periods to enable precise estimation of planting times (Nangimah et al., 2018). The equilibrium between incoming and outgoing water within a certain time span on a plot of land is dynamic, and it always changes with time, which may cause water shortage or excess (Paski et al., 2018). Based on climatic equilibrium, the land water balance is strongly influenced by precipitation and evapotranspiration factors. The comparison of these two factors will affect other parameters, such as water surplus, water deficit, and soil water content (Thornthwaite & Mather, 1957) Soil water balance, which is part of the land water balance, is used to evaluate the possible reduction in yield caused by soil water deficit impacting crops. This is a consequence of declining water presence in the soil layer due to evaporation, root absorption, and water movement to other layers (Ritchie, 1998).

Analysis of land water balance becomes crucial because it helps estimate soil water availability for crops in a particular period, so that proper management can be implemented when water availability is insufficient(Ensafi Moghaddam & Mohammadkhan, 2017; Mammoliti et al., 2021; A. R. Nugroho et al., 2019). By understanding the land water balance, farmers can optimize planting time planning so they can avoid crop failure risk due to deficits and therefore maximize agricultural production (Chandrasekar et al., 2012; Todorovic, 2016). In practice, planting seasons are often poorly planned, leading to disparities between soil water availability and the water needed by crops. By determining planting seasons more accurately through simulations of land water balance, more precise predictions of soil water conditions can be generated for each month, resulting in more optimal planting season determination(Mardawilis et al., 2012; Musyadik et al., 2023; Osorio et al., 2014; Pratiwi & Nasrul, 2022). This directly contributes to increased agricultural productivity and is expected to enhance food security, ensuring adequate food availability for the community. By utilizing water resources efficiently and reducing dependence on artificial irrigation, national food independence can be improved. In addition, it supports the government in achieving food sovereignty through the sustainable use of natural resources.

Rambipuji District is one of the supporting districts for the national food supply, serving as a rice barn for Jember Regency (BPS Kabupaten Jember, 2025). However, based on research by Lukman (2021), Rambipuji is one of the areas frequently affected by drought, causing many agricultural lands to be damaged. Furthermore, based on information from (BPBD Jember, 2023), Rambipuji again experienced severe drought in the dry season of 2023. Based on these conditions, the agricultural sector in Rambipuji District may be threatened in its sustainability. The agricultural lands in Rambipuji are dominated by irrigated rice fields and rain-fed rice fields, indicating that managing agricultural water use is critical, especially to increase water availability in the face of the dry season. One initial step to optimize water use is to determine water availability conditions in Rambipuji's agricultural land through land water balance analysis, which generally provides information on when water shortage or excess occurs. By knowing these conditions, cropping patterns and irrigation schedules can be optimized.

Land water balance can be carried out by adapting the Thornthwaite Mather 1957 method, the most widely used general method for modeling land water balance to estimate rapid water exchange in soil (Dwiratna et al., 2025). This balance is also used to estimate the total water availability in soil and, indirectly, to calculate crop water requirements (Costa et al., 2018). Water balance is essential because it provides information about soil water, soil water conditions in the root zone for different soils and crops, and helps design irrigation schedules (Todorovic, 2016; Zheng et al., 2025). Water balance can be calculated for daily or monthly periods. The required data include average air temperature, average monthly rainfall, and water holding capacity information for a specific soil depth in the study area (Sabaruddin et al., 2021).

In Indonesia, the Thornthwaite Mather method is applied to determine crop water requirements during cultivation. For example, Sitanggang et al. (2022) used the Thornthwaite Mather water balance to identify surplus and deficit periods for sweet corn crops to guide irrigation and mulching, aiming to increase sweet corn production; and Laimeheriwa et al. (2022) analyzed land water balance at soil depth of 0-20 cm. Research in the Parigi District applied land water balance on developed soils with Karts parent material, showing surplus periods from February to April (Tufaila et al., 2017); analysis of water balance in the Bengkulu sub-watershed used the Thornthwaite method to calculate average monthly water discharge (Ramadhan et al., 2022). Other studies analyzed land water balance for scheduling planting times of food crops on dryland (Yunatas et al., 2021), and for upland rice in Sub-Watershed Wolasi (Fitria Sani et al., 2024). That studies analyzed land water balance in general, previous studies have generally been conducted at macro scales (district or watershed level), not focusing on spatial details that could be directly used by each farmer's land for local policy decisions.

The distinction between this study and previous research lies in the approach used for water balance analysis. Previous studies, such as those conducted by (Sofia et al., 2019), analyzed water balance based solely on rainfall and evapotranspiration parameters. In contrast, this study applies the Thornthwaite–Mather method by incorporating more comprehensive parameters, including not only rainfall and evapotranspiration but also soil conditions through water holding capacity analysis. Water holding capacity analysis is essential to determine the soil's ability to retain water, which plays a crucial role in fulfilling crop water requirements, as water availability largely depends on the water stored within soil pores. Furthermore, studies by (Paski et al., 2018),Uspessy et al., (2020), (Laimeheriwa et al., 2022), (Madubun et al., 2024) and (Delianata et al., 2025) also employed the Thornthwaite–Mather method for water balance analysis in food crops. However, their estimation of soil moisture was not based on actual field conditions and remained general in scope, without specific focus on agricultural land areas.

Therefore, this study addresses this gap by conducting a more site-specific analysis focused on agricultural land. These characteristics are defined using land mapping units, which include soil type, agricultural land use, and slope, all of which significantly influence soil water holding capacity. Soil moisture data are obtained directly through soil sampling to determine water holding capacity based on land characteristics. Thus, it provides more specific local land-based information, where each land with different characteristics also shows different soil water levels. This study also provides spatial mapping of the early cropping season and cropping pattern in Rambipuji District, which has not been presented in previous similar studies. This research provides a novelty of land water balance analysis for optimizing cropping season and pattern at the agricultural land level by detailing land and soil characteristics and spatially based distribution of early cropping season, thereby filling the information gap on the spatial distribution of soil water availability for local planting season determination. This study aims to analyze the water balance in agricultural land using the Thornthwaite–Mather method by incorporating not only rainfall and evapotranspiration parameters but also soil characteristics through water holding capacity analysis, and provide its spatial distribution.

2. Material and Methods

2.1 Materials

This research was conducted in Rambipuji District, Jember Regency, the research was conducted between April 2025 and November 2025. The data utilized in this study comprise rainfall records (monthly averages over the last 10 years), as well as meteorological parameters including air temperature, relative humidity, sunshine duration, and wind speed, all of which were obtained from the BMKG East Java Climatology Station), soil samples for land water balance analysis were selected based on Land Unit Maps (LUMs), as presented in Figure 1, which were generated through the overlay of soil type, agricultural land use, and slope maps using a Geographic Information System (GIS)-based technique. Based on the integrated analysis of these land characteristics, a total of five Land Mapping Units (LMUs) were delineated. The integration of slope, soil type, and land use enabled the identification of spatially homogeneous units representing distinct land characteristics within the study area. Accordingly, the maximum number of LMUs that can be delineated is inherently dependent upon the degree of spatial variability exhibited by these defining land characteristics. From each LMU, one representative soil sampling point was selected using a random sampling approach to ensure adequate representation of each unit. The collected soil samples were subsequently subjected to laboratory analysis to determine soil texture and water holding capacity (WHC).

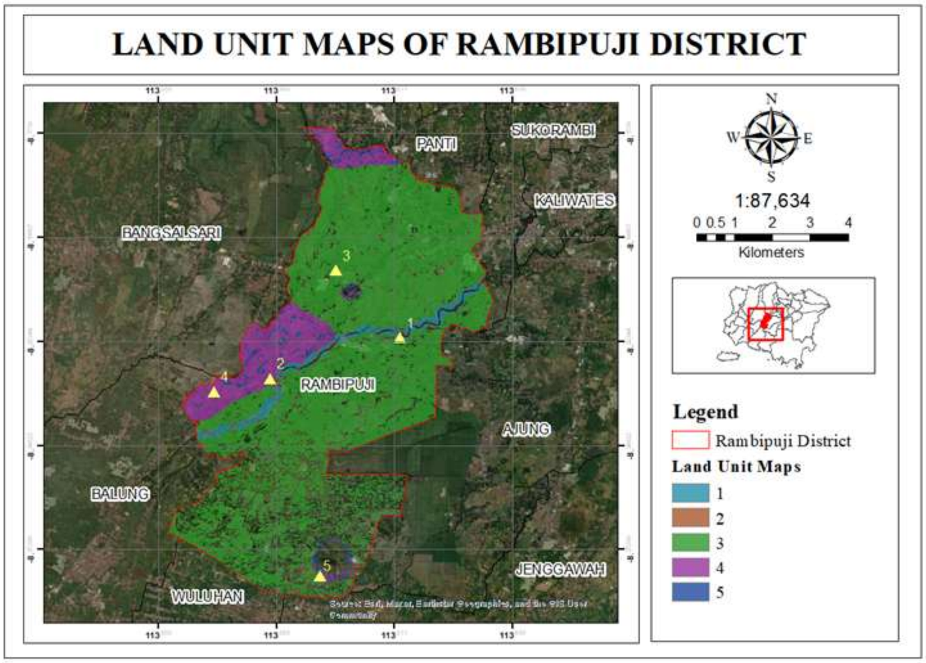


Figure 1. Land Unit Map Of the Study Area.

2.2 Methods

2.2.1 Land Water Balance Method

The method employed for optimizing the cropping pattern was the Thornthwaite-Mather method (1957), the monthly water balance analysis over 12 months. The data required included average evapotranspiration, average monthly rainfall, and information on water holding capacity at a soil depth of 0–20 cm within the study area. The land water balance is compiled based on the three variables described above. The steps involved are shown below.

1. Compile a monthly water balance table (Table 1)

Table 1. Monthly Water Balance Table

	Jan	Feb	Mar	Apr	May	Juni	July	Aug	Sep	Oct	Nop	Des
P												
P_{eff}												
ETo												
ETc												
P_{eff} - ETc												
APWL												
SM												
ΔSM												
ETa												
Deficits												
Surplus												

2. Fill in the Precipitation (P) and Effective Rainfall (Peff) Columns

   The climatological data derived from monthly rainfall observations were averaged to determine the mean monthly rainfall. Subsequently, the effective rainfall (P_eff)was calculated using the following formula (Brouwer & Heibloem, 1986b):

   $$P_{eff} = 0.8\,P_{mean} - 30 \qquad \text{if } P > 75 \text{ mm/month} \tag{1}$$

   $$P_{eff} = 0.6\,P_{mean} - 10 \qquad \text{if } P < 75 \text{ mm/month} \tag{2}$$

   Where Peff is the effective rainfall, and Pmean denotes the average monthly climatological rainfall.

3. Fill in the Eto, Etc colomns

   The reference evapotranspiration (ETo) rate is determined using meteorological data processed by the ETo Calculator software, employing the FAO Penman-Monteith method as the standard procedure. Subsequently, crop evapotranspiration (ETc) is calculated using the following equation (Allen et al., 1998).

   $$ET_c = K_c\, x\, ET_0 \tag{3}$$

   Where ETc refers to crop evapotranspiration (mm day^{-1}), Kc is the crop coefficient based on FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998). In this study, Kc values for rice paddy were determined according to each respective growth stage, and ETo is the reference evapotranspiration (mm day^{-1}) as shown in Table 2 below.

Table 2. Kc Value for Paddy Field.

	Padi	
Phase	**Period**	**Kc**
Initial	30	1.05
Development	30	1.2
Middle Sesason	60	1.2
Late Season	30	0.9

Source: Data Analysis, 2025.

4. Calculating P_{eff}-ETc
5. Fill in the Accumulation Potential Water Loss (APWL) column, which is the accumulation of negative values on Peff - ETc, which are accumulated from month to month.
6. Determine the value of soil water content or soil moisture (SM) in the 1st month

   Soil Moisture (SM) is determined based on the soil water content at water holding capacity within the root zone, specifically when the Peff - ETc value is positive.
7. Soil moisture (SM) was determined using the APWL method, calculated sequentially from the first to the last month of the APWL period, applying the following equation (Hendrayana et al., 2021; R. Nugroho & Savitri, 2017).

$$SM = WHC \cdot e^{APWL/WHC} \tag{4}$$

Where SM is Soil moisture (mm), WHC is water holding capacity (mm), and APWL is accumulation potential water loss.

8. If the soil moisture (SM) value under APWL conditions has been calculated entirely, then sum with the positive values of (P_{eff} -ETc). If the accumulated SM value for the nth month with (P_{eff} - ETc) (n+1)th month during a period with a positive (P_{eff} - ETc) exceeds WHC, then set SM equal to the value of WHC.
9. Determibe the change in SM (ΔSM) each month until the last month.
10. Fill in the Actual Evapotranspiration (ETa) column

If $P_{eff} > ETc$, then $ETa = ETc$ (5)

If $P_{eff} < ETc$, then $ETa = P_{eff} + |\Delta \mathrm{SM}|$ (6)

11. Fill in the Defiicit Column (D)

$$D = ETc - ETa \tag{7}$$

12. Fill in the Surplus Column (S)

$$S = P_{eff} - ETc - \Delta \mathrm{SM} \tag{8}$$

2.2.2 Determination Early Cropping Season

The cropping season in five sample areas in Rambipuji District was determined based on several criteria, based on Laimeheriwa et al. (2022) :

1. The period when soil water content reaches optimum conditions, i.e., SM = WHC
2. The months before and after the optimum SM have a P_{eff}/ETc ratio of ≥ 0.75

3. Results and Discussion

The determination of land water balance, cropping pattern, and the beginning of the planting season in Rambipuji Sub-district, Jember Regency, was conducted on five land units located on slope conditions ranging from 0% to 15%, which fulfill the growth requirements for food crops (Gasparini et al., 2026). These land units represent different land characteristics, as presented in Table 3.

Table 3. Land Unit Maps: Characteristics of Rambipuji District.

LUM	Slope Classes	Soil Order	Subgroup	Land Use	Area (Ha)
1	0 - 8%	Inceptisols	Fluvaquentic Endoaquepts	mixed upland agriculture	147.759
2	8 - 15%	Inceptisols	Fluvaquentic Endoaquepts	mixed upland agriculture	23.364
3	0 - 8%	Inceptisols	Typic Epiaquepts	Paddy field	3,612.740
4	0 - 8%	Inceptisols	Typic Eutrudepts	Paddy field	486.948
5	8 - 15%	Inceptisols	Typic Eutrudepts	mixed upland agriculture	102.914

Source: Data Analysis, 2025.

The soil type in Rambipuji Sub-district is classified as Inceptisols, with soil characteristics that indicate profile development and occur on sloping land with varying drainage and fertility conditions (Rahmayuni et al., 2023). The subgroups identified at the study site are Fluvaquentic Endoaquepts, Typic Epiaquepts, and Typic Eutrudepts. Fluvaquentic Endoaquepts are found in LUM 1 and 2; although this soil subgroup is characterized by impeded drainage, mixed upland agriculture can still be practiced, provided that appropriate drainage management and soil conservation measures are implemented (Sirappa & Susanto, 2008). In LUM 3 and 4, the same land use, namely paddy fields, is found, but these two LUMs have different soil subgroups, namely Typic Epiaquepts and Typic Eutrudepts. Soils of the Typic Epiaquepts subgroup are suitable for flooded rice fields because they are episaturated, whereas Typic Eutrudepts are more suitable for mixed upland agriculture but can still be used for flooded rice cultivation under good water management; this soil subgroup has high fertility that supports increased crop productivity (Hadi et al., 2019). In LUM 5, the Typic Eutrudepts subgroup is also found, which is highly recommended for mixed upland agriculture crops (Soil Survey Staff, 2022; Susanto & Sunarminto, 2013).

Rainfall is a critical parameter in agricultural systems, particularly in relation to plant growth, as it directly influences soil water availability (Kheyruri et al., 2024; Madubun et al., 2024). In rain-fed agriculture, rainfall constitutes a key determinant of crop production (Zike, 2019). To assess the impact of rainfall on groundwater resources, land water balance calculations can be conducted. Understanding both the quantity and distribution of rainfall, as well as the length of the crop growth period, enables farmers to mitigate crop losses stemming from climate anomalies (Bedane et al., 2022). Based on the rainfall analysis shown in Figure 2, the 10-year (2015–2024) average monthly rainfall shows the highest value in January at 380 mm/month, while the lowest occurs in August at 27 mm/month. The rainfall pattern at the study site is classified as a monsoonal pattern, with a single peak of rainfall occurring in January and a single peak of the dry season occurring in August.

The portion of rainwater that infiltrates and is stored within both micro and macropores is referred to as effective rainfall, which refers to the proportion of total rainfall available for direct or indirect use in crop production. The highest rainfall occurs in January, reaching 280 mm, while the lowest is recorded in August at 6.2 mm. Determining the effective rainfall helps estimate soil water availability. When rainfall meets crop water requirements, irrigation is unnecessary; otherwise, supplementary irrigation is necessary to fulfill crop water needs (Ali & Mubarak, 2017). According to Koesmaryono & Askari (2023), lowland rice relies on almost all effective rainfall supplied, whereas highland and secondary crops may require less.

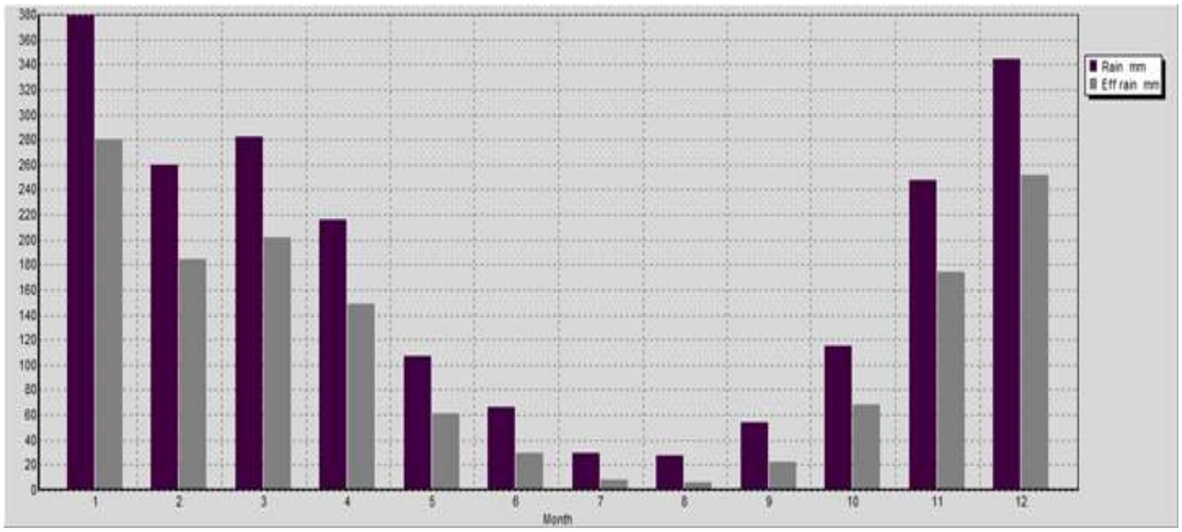


Figure 2. Rainfall and Rainfall Effective Distribution

Evapotranspiration refers to the quantity of water lost simultaneously from plants, plant tissues, and soil (Ahmad Fausan et al., 2021; Allen et al., 1998; Fitriani et al., 2024; Paredes et al., 2020). As a fundamental component alongside rainfall, evapotranspiration significantly influences irrigation systems and planting practices (Aydın, 2021). The measurement of evapotranspiration values is essential for optimizing irrigation management efficiency, chiefly by enhancing water use (Osorio et al., 2014; Zheng et al., 2016).

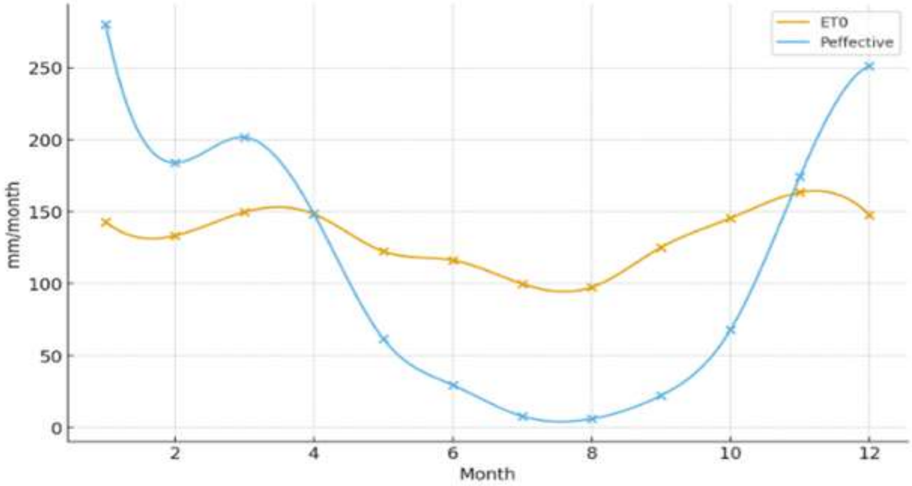


Figure 3. Comparison Of ET0 and Peff

Based on Figure 3, the highest evapotranspiration occurs in October, with an average monthly total of 163.37 mm, while the lowest occurs in July at 97.65 mm. In general, the difference between ETO values and effective rainfall indicates whether the soil water availability is in surplus or deficit.

According to the graph, a water surplus occurs from November to April, whereas a deficit or water shortage begins from May to October.

The crop evapotranspiration rate is determined by calculating the reference evapotranspiration and applying the crop coefficient (Kc). The Kc values used in this study are taken from the FAO Irrigation and Drainage Paper 56 (Allen et al., 1998), which indicates that paddy has one of the highest crop coefficients, implying that rice requires more water than most other crops. Paddy rice cultivation with the traditional flooding method needs a lot of water (Bwire et al., 2024; Wu et al., 2025). Therefore, the determination of ETc parameters applies the paddy Kc for each growth stage. In case Rambipuji District shows that average relative humidity exceeds 80% and wind speed is less than 2 m s^{-1}, then the Kc value should be reduced by 0.05 under conditions of relative humidity greater than 80% and wind speed below 2 m s^{-1} (Brouwer & Heibloem, 1986a).

3.1 Water Holdiing Capacity

Soil water content, or soil moisture, greatly affects plant growth, and management methods and slope gradients also affect soil water content (Horel & Zsigmond, 2023). After rain or irrigation stops, some water will move downwards during the percolation or drainage process, so that some pores will be filled with air. In this condition, the water holding capacity or water holding capacity is achieved, the condition where percolation stops. In this condition, the water and air content in the soil reaches the ideal point for plants (Abdallah et al., 2021). Table 4 summarizes the variation in field capacity (total water-holding capacity at 0–20 cm depth) among different soil textures at the study site, highlighting how texture controls soil water storage in the root zone.

Table 4. Variation of water-holding capacity

LUM	Texture	Water holding capacity (mm)
1	Sandy Clay	94.77
2	Sandy Clay Loam	105.85
3	Clay Loam	112.43
4	Clay	110.62
5	Sandy Clay Loam	93.01

Source: Data Analysis, 2025

Results of the water holding capacity analysis at five soil sampling points (LUM) in agricultural land in Rambipuji District showed variations in values according to the observed soil texture, ranging from Sandy Clay to Clay Loam. Water holding capacity values (mm) ranged from 93.01 for Sandy Clay Loam (LUM 5) to 112.43 for Clay Loam (LUM 3). In general, these differences are strongly controlled by the particle-size fractions that define soil texture, particularly the relative proportions of clay, sand, and silt. They may also be modified by soil structure, organic matter content, and land-use or cultivation history (Li et al., 2024; Wang et al., 2020). The highest water holding capacity values were found in Clay Loam (112.43 mm) at LUM 3 and Clay (110.62 mm) at LUM 4. This pattern is consistent with the theory that more clay-rich soils contain a greater proportion of micropores, enabling them to retain more water after rainfall or irrigation(Johnson, 2023; Zhang et al., 2021). Previous research has shown that soil porosity directly influences the soil's water holding capacity (WHC), with a positive correlation observed between these variables (Sahu et al., 2022). Furthermore, soil texture, which determines the distribution and size of pores, plays a critical role in defining WHC (Franzluebbers, 2020; Sinkevičienė et al., 2024). Clay-textured soils are predominantly composed of micropores, which have a strong ability to retain water; consequently, clay soils can store water for longer periods but because the water is adequate in the micropores, it makes it very difficult for plant roots to absorb water(Harefa, 2025; Sinkevičienė et al., 2024). In contrast, sandy soils contain a higher proportion of macropores, which facilitate rapid drainage and result in lower water retention capacity. This finding is consistent with previous research indicating that soils with greater macropores tend to exhibit reduced water holding capacity (Sinkevičienė et al., 2024). Such high-water retention capacity is critical for maintaining a longer-lasting water supply for plants, especially during dry periods or when rainfall is insufficient (Stone et al., 2025).

3.2 Land Water Balance

Aroma is the first sensory profile detected by the human senses, thus playing an important role in determining the impression and level of enjoyment of coffee drinks. The cupping score (Figure 1) for the aroma parameter was 8.0, which shows that Lahat Robusta coffee from South Sumatra has an advantage in terms of aroma. Aroma characteristics are developed during the roasting process through a series of chemical reactions, such as the Maillard reaction and the degradation of precursor components, such as amino acids, trigonelline, sugars, and phenolic compounds, which play a role in aroma formation (Rahayu et al. 2023). Aroma is the main differentiator between specialty and non-specialty coffee and is a determining factor in consumer preferences. The strength of coffee aroma originates from the volatile components formed during the roasting process. Chindapan et al. (2021) stated that the aroma profile consists of various chemical compounds, such as sulfur, pyrazine, pyridine, pyrrole, oxazole, furan, aldehyde, ketone, and phenol, which impart unique/authentic characteristics.

The formation of aroma precursors can occur due to metabolic activity during natural post-harvest processing, which causes the interconversion of low-molecular-weight sugars and protein hydrolysis in the formation of precursor compounds, such as aldehydes, ketones, and alcohols, which undergo transformation through Maillard reactions and thermal degradation during roasting (Zhang et al. 2023). Research (Moon et al. 2023) has reported that volatile compounds such as pyrazines, ketones, aldehydes, heterocyclic nitrogen compounds, acetates, acids, alcohols, esters, and furans act as marker compounds in coffee. Improvements in coffee aroma quality are related to postharvest processing practices. Fardenan et al. (2024) reported that soaking in 3% acetic acid can improve the profile of unripe robusta beans by optimizing flavor precursor components and reducing chlorogenic acid. The superior aroma of robusta coffee has the potential for product diversification, despite limitations in flavor intensity due to its high caffeine content. Therefore, the consistent application of post-harvest technology is a key factor in minimizing coffee-bean damage.

As an illustration of the water balance analysis, a water balance table will be presented for LUM 3, which is characterized by a clay loam soil texture, a slope gradient of 0–8%, an Inceptisols Typic Epiaquepts soil type and subgroup, and paddy field land use, as shown in Table 5 below. The other LUMs will be presented in the form of graphs showing the monthly deficit and surplus conditions in Figures 4a – 4d.

Table 5. Land Water Balance at LUM 3

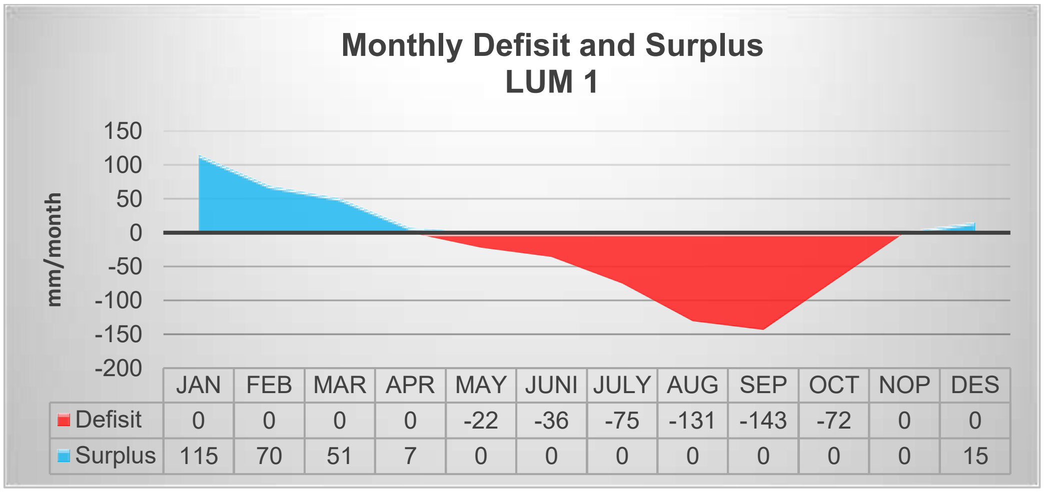
MONTH												
	1	2	3	4	5	6	7	8	9	10	11	12
P	380	260	282	216	107	66	30	27	54	115	248	344
Peff	279	183	201	148	61	30	8	6	22	67	173	250
Eto	143	133	150	122	116	100	98	125	146	163	148	145
Etc	164	113	150	141	134	85	98	144	167	139	148	166
Peff-Etc	115	70	51	7	-73	-55	-90	-138	-145	-72	26	84
APWL	0	0	0	0	-73	-128	-218	-356	-501	-573	0	0
SM	112	112	112	112	58	36	16	5	1	1	26	110
ΔSM	0	0	0	0	-54	-23	-20	-11	-3	-1	26	84
Eta	164	113	150	141	114	53	28	17	26	67	148	166
Deficits	0	0	0	0	19	32	70	127	142	71	0	0
Surplus	115	70	51	7	0	0	0	0	0	0	0	0

Source: Data Analysis, 2025

The Land Water Balance Analysis Table for LUM 3 presents, in a sequential manner, the dynamics of soil water availability and the agricultural water cycle throughout the year, along with their implications for land management. From January to April, the Peff values remain very high, resulting in successive water surpluses of 115 mm, 70 mm, 51 mm, and 7 mm. During this phase, Soil Moisture (SM) is stable at 112 mm, indicating that the soil is consistently at an optimum level (near water holding capacity), so the growth of rice or other water-demanding crops can proceed very well without experiencing water shortage. Entering May, the pattern begins to change, the value of Peff becomes lower than crop evapotranspiration (ETc), as indicated by Peff - ETc turning negative, followed by a sharp decline in SM from 112 mm to 58 mm (May), 36 mm (June), and only 15 mm (July). This condition triggers a water deficit starting from 19 mm in May, increasing to 32 mm in June, 70 mm in July, and reaching its peak in August and September with 127 mm and 142 mm, respectively. During this period, SM remains only around 6 mm to 1.3 mm, rendering the land highly vulnerable for crop growth; physiologically, plants can experience severe water stress, which may significantly reduce yields and can even lead to crop failure if no adequate mitigation measures are implemented (Syaripah Najihah et al., 2019; Wadood et al., 2024).

Figure 4 showed that the water balance analysis revealed a strong seasonal pattern controlled by the monsoon climate, with a dominant water surplus during the January–March period and a peak in January. This reflects rainfall significantly exceeding potential evapotranspiration, resulting in replenishment of soil moisture and land water reserves (Xu & Singh, 2005). The water surplus began to decline in April, and all LUMs experienced deficits from May to October, peaking in September. This pattern aligns with the characteristics of a tropical monsoon climate, which is characterized by a dry season with limited water availability (Wang et al., 2020)

Differences in the duration and intensity of deficits across LUMs indicate the influence of land use and management on hydrological responses. LUMs with longer deficit durations indicate lower water storage capacity and greater vulnerability to seasonal droughts. These findings underscore the importance of water balance information as a basis for determining cropping calendars and agricultural adaptation strategies to future climate variability and change (Allen et al., 1998; IPCC, 2023) and the identification of water surplus and deficit periods can support the development of an appropriate irrigation schedule, particularly in areas experiencing water deficit(Zhou & Zhao, 2019) as observed in this study.

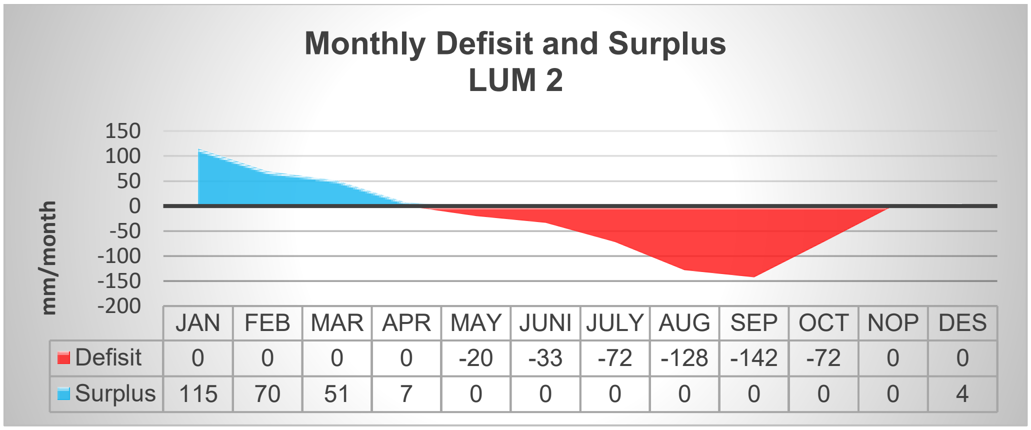


	JAN	FEB	MAR	APR	MAY	JUNI	JULY	AUG	SEP	OCT	NOP	DES
🟥 Defisit	0	0	0	0	-22	-36	-75	-131	-143	-72	0	0
🟦 Surplus	115	70	51	7	0	0	0	0	0	0	0	15

(a)

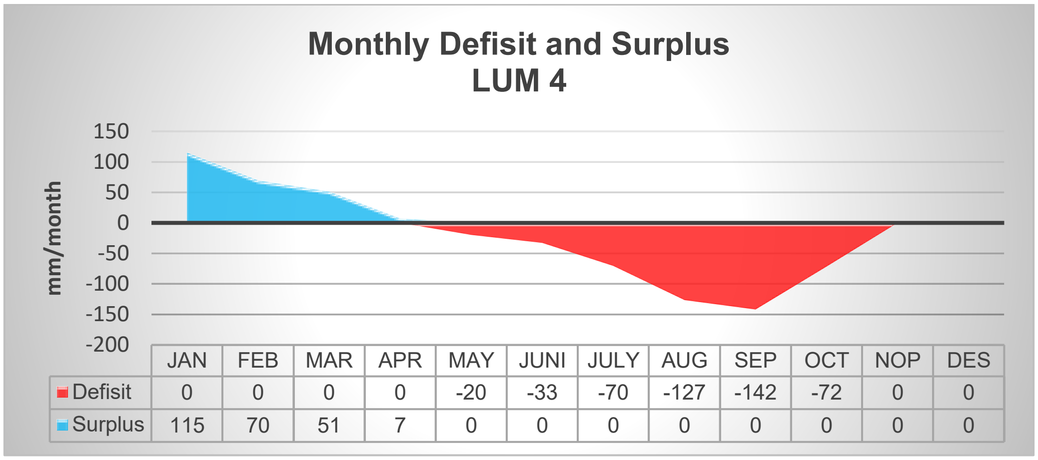
Continue

Continue


Monthly Defisit and Surplus
LUM 2

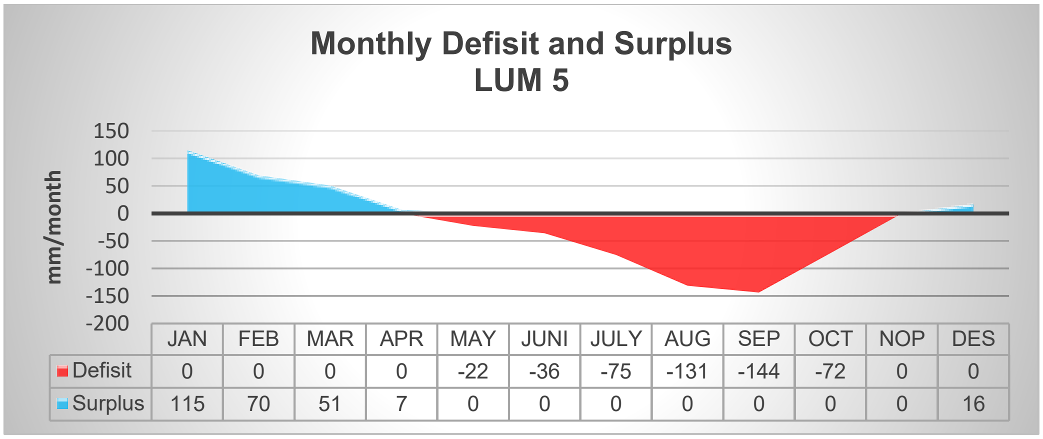
	JAN	FEB	MAR	APR	MAY	JUNI	JULY	AUG	SEP	OCT	NOP	DES
🟥 Defisit	0	0	0	0	-20	-33	-72	-128	-142	-72	0	0
🟦 Surplus	115	70	51	7	0	0	0	0	0	0	0	4

(b)


Monthly Defisit and Surplus
LUM 4

	JAN	FEB	MAR	APR	MAY	JUNI	JULY	AUG	SEP	OCT	NOP	DES
🟥 Defisit	0	0	0	0	-20	-33	-70	-127	-142	-72	0	0
🟦 Surplus	115	70	51	7	0	0	0	0	0	0	0	0

(c)


Monthly Defisit and Surplus
LUM 5

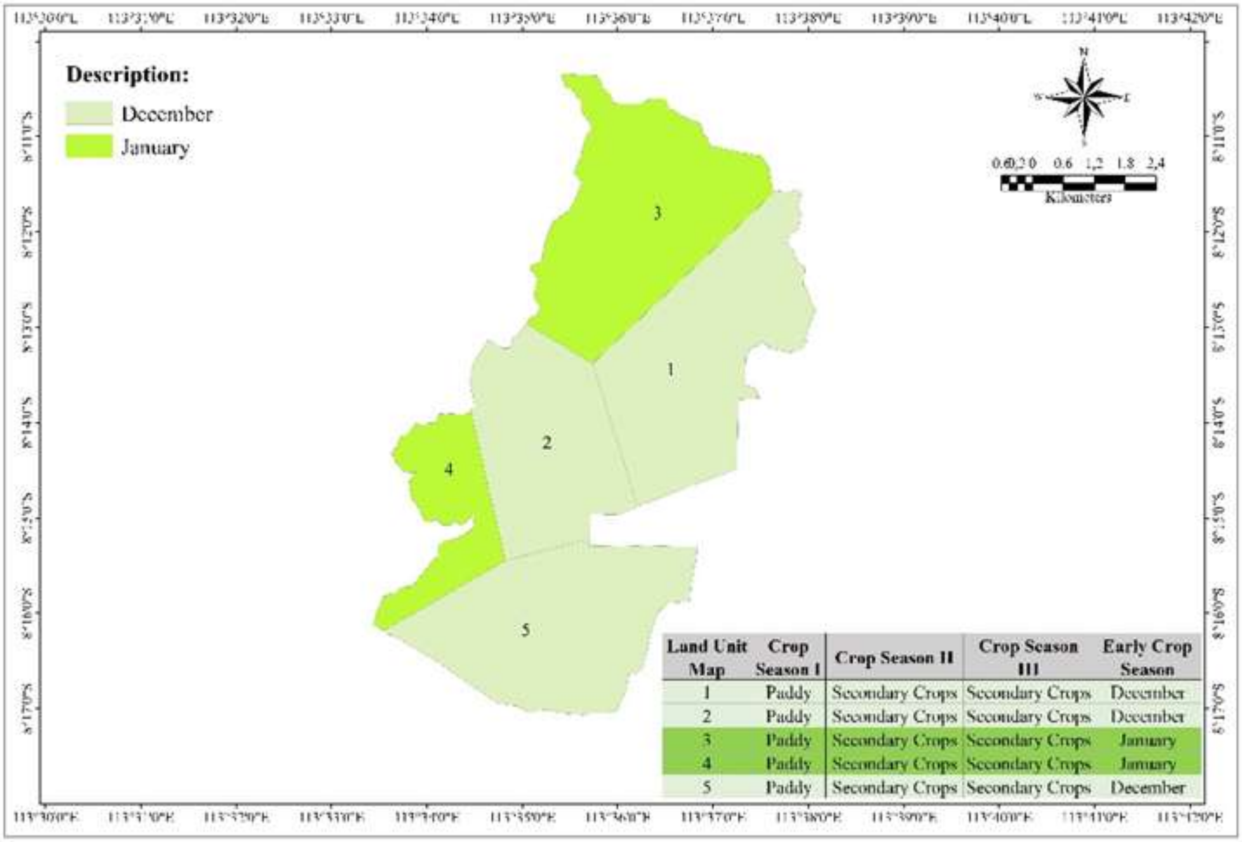
	JAN	FEB	MAR	APR	MAY	JUNI	JULY	AUG	SEP	OCT	NOP	DES
🟥 Defisit	0	0	0	0	-22	-36	-75	-131	-144	-72	0	0
🟦 Surplus	115	70	51	7	0	0	0	0	0	0	0	16

(d)

Figure 4. Monthly Deficits and Surpluses for different LUM (a) LUM 1, (b) LUM 2, (c) LUM 4, and (d) LUM 5

3.3 Cropping Schedule

The recommended planting onset for each land mapping unit reflects the interaction between soil water availability and climatic controls. Based on land water balance analysis and planting onset criteria defined by soil water content reaching water holding capacity, and a P_{eff} /ETc ratio ≥ 0.75. As Figure 5 shows, LUM 1, 2, and 5 are suitable for planting in December, whereas LUM 3 and 4 are more appropriate in January. These conditions indicate sufficient soil water reserves and effective rainfall to support early paddy establishment while reducing the risk of water-deficit stress. The subsequent shift to secondary crops in planting seasons II and III represents an adaptive response to declining rainfall, optimizing water-use efficiency in accordance with soil water storage capacity across land units, as showed at figure 6. This synchronized paddy–secondary crop pattern demonstrates strong consistency with local agroclimatic conditions and field-based water balance principles, supporting its relevance for precision-oriented cropping system planning.



Land Unit Map	Crop Season I	Crop Season II	Crop Season III	Early Crop Season
1	Paddy	Secondary Crops	Secondary Crops	December
2	Paddy	Secondary Crops	Secondary Crops	December
3	Paddy	Secondary Crops	Secondary Crops	January
4	Paddy	Secondary Crops	Secondary Crops	January
5	Paddy	Secondary Crops	Secondary Crops	December

Figure 5. Distribution of Early Cropping Season in Rambipuji

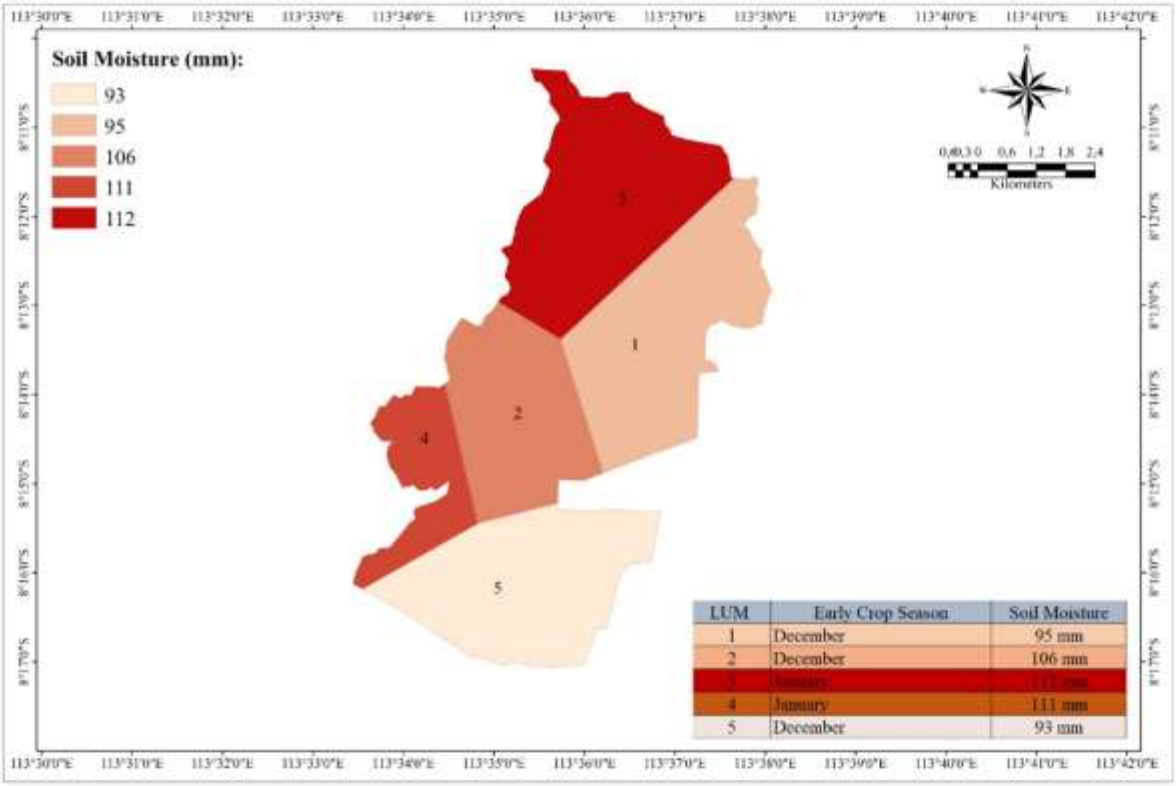


Figure 6. Distribution Of Soil Moisture at Early Cropping Season.

4. Conclusion

Robusta coffee from Lahat, South Sumatra, has superior quality and meets specialty coffee standards (fine robusta) with a final cupping score of 83.88. Natural post-harvest processing produces optimal consistency and uniformity of flavor, represented by a score of 10 (outstanding) for the uniformity and clean cup parameters. This study proves that proper post-harvest processing is correlated with superior coffee quality. The cupping results obtained a sensory profile dominated by characteristics of brown sugar, honey, dark chocolate, hazelnut, fresh fruity, nutty, acidic, cereally, and spicy. These results can be used as a starting point to identify the uniqueness of Lahat Robusta coffee from South Sumatra.

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6. AI Writing Statement

The authors used AI-powered tools just to help make the language clearer, fix grammar issues, make the text easier to read, and organize the manuscript better. All the scientific ideas, how the study was planned, how data was gathered, how the data was looked at, what the results mean, and the conclusions were completely made and checked by the authors themselves. The authors are completely responsible for making sure the information in this manuscript is correct, unique, and honest.

7. References

Abdallah, A. M., Jat, H. S., Choudhary, M., Abdelaty, E. F., Sharma, P. C., & Jat, M. L. (2021). Conservation agriculture effects on soil water holding capacity and water-saving varied with management practices and agroecological conditions: A Review. Agronomy, 11(9), 1681. https://doi.org/10.3390 /agronomy11091681

Ahmad Fausan, Setiawan, B. I., Arif, C., & Saptomo, S. K. (2021). Evaporation and evapotranspiration model analysis using mathematical modeling in visual basic in maros regency. Jurnal Teknik Sipil Dan Lingkungan, 5(3), 179–196. https://doi.org/10.29244/jsil.5.3.179-196

Ali, M., & Mubarak, S. (2017). Effective rainfall calculation methods for field crops: an overview, analysis, and new formulation. Asian Research Journal of Agriculture, 7(1), 1–12. https://doi.org/10.9734/arja/ 2017/36812

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56 (Vol. 17). FAO - Food and Agriculture Organization of the United Nations. https://www.researchgate. net/publication/235704197

Aydın, Y. (2021). Assessing evapotranspiration models using limited climatic data in the Southeast Anatolian Project Region of Turkey. PeerJ, 9, e11571. https://doi.org/10.7717/peerj.11571

Bedane, H. R., Beketie, K. T., Fantahun, E. E., Feyisa, G. L., & Anose, F. A. (2022). The impact of rainfall variability and crop production on vertisols in the central highlands of Ethiopia. Environmental Systems Research, 11(1), 26. https://doi.org/10.1186/s40068-022-00275-3

BPBD Jember. (2023). Drought in parts of Jember Regency has caused 1,316 families to lack clean water. PPID JEMBER. https://ppid.jemberkab.go.id/berita/kekeringan-di-sebagian-wilayah-kabupaten-jember-menyebabkan-1316-kk-kekurangan-air-bersih#:~:text=Semua%20Agenda%20Bulanan-,Kekeringan%20di%20sebagian%20wilayah%20Kabupaten%20Jember%20menyebabkan%201.316%20KK%20Kekurangan,110%20santri%20Ponpes%20At%20Thohiriyah.

BPS Kabupaten Jember. (2025). Rambipuji District in Figures 2025: XXXIX (BPS Kabupaten Jember, Ed.). BPS Kabupaten Jember. https://web-api.bps.go.id/download.php?f=

VVidc5MxRBJ5AfqNimflmkNCOUY4dURIbVl4Rjh1cEFoY0pxUjhFd1RGWUhXLzVoODdrSERud1ZiMGZYbmlHVm1XTzBJc1JtT1EzRWs4Qk9EWUVxTk05RGpzRGI2WjBqR3FyeFM4UFh5OHQzZEQwLzVNUlFmcHlpSjBreDladCthYlJVT3IrQ2VUMnZPa1VpOUxvNDJTdkNkQTdDNU9rakxCblU5RlhPZUNIZEs4ZmhEcS81akZmMWRyK3ErQVZLcXpjSFZvNG5rbDhlc3dPdHhsYmJzY2c0cFg1Nm5YeTZ0Rnc1aUxBdmhjcnUzc0ZMMWhIRVdvQmw2VHFVYkw1MEY1QkQzTThZbDNpQW0yNTg=

Brouwer, C., & Heibloem, M. (1986). Irrigation water management training manual No. 3: Irrigation Water Needs. FAO. Fao.Org. https://www.fao.org/4/s2022e/s2022e00.htm#Contents

Bwire, D., Saito, H., Sidle, R. C., & Nishiwaki, J. (2024). Water management and hydrological characteristics of paddy-rice fields under alternate wetting and drying irrigation practice as climate smart practice: a review. Agronomy, 14(7), 1421. https://doi.org/10.3390/agronomy14071421

Chandrasekar, K., Sesha Sai, M. V. R., & Behera, G. (2012). Assessment of early season agricultural drought through land surface water index (lswi) and soil water balance model. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVIII-8/W20, 50–55. https://doi.org/10.5194/isprsarchives-xxxviii-8-w20-50-2011

Costa, J. M., Egipto, R., Silvestre, J., Lopes, C. M., & Chaves, M. M. (2018). Water and heat fluxes in mediterranean vineyards. In Water Scarcity and Sustainable Agriculture in Semiarid Environment (pp. 219–245). Elsevier. https://doi.org/10.1016/B978-0-12-813164-0.00010-7

Delianata, S. S., Hariyono, D., & Fajriani, S. (2025). Analysis of soil water balance to determine the planting period of rice in rainfed. Journal of Agricultural Science, 2025(1), 32–41. https://doi.org/10.21776/ub.jpt.2025.010.1.4

Dwiratna, S., Ayu, Y. L., Asdak, C., & Pithaloka, N. A. (2025). Water balance analysis using the thornthwaite-mather method as a basis for cropping pattern development in dry land. Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering), 14(2), 547. https://doi.org/10.23960/jtep-l.v14i2.547-559

Ensafi Moghaddam, T., & Mohammadkhan, S. (2017). An estimation of Thornthwaite's monthly water balance in the Mighan sub-basin. Natural Environment Change, 3(1), 71–80. https://doi.org/10.22059/ jnec.2017.216461.54

Fitria Sani, N., Darwis, D., Alam, S., Rustam, R., Leomo, S., & Erawan, D. (2024). Land water balance analysis for upland rice and corn crop planning in the wolasi sub-das. AGRONU: JURNAL AGROTEKNOLOGI, 3.

Fitriani, V., Gandri, L., Bowo, C., & Mandala, M. (2024). Comparison of empirical methods to estimate reference evapotranspiration. Jurnal Ilmiah Rekayasa Pertanian Dan Biosistem, 12(2), 177–192. https://doi.org/10.29303/jrpb.v12i2.629

Gasparini, J. L. G., Branco, D. A. C., & Szklo, A. (2026). Soil suitability and technical-construction criteria for slope classification in agrivoltaic systems. Solar Energy, 308, 114335. https://doi.org/10.1016/ j.solener.2026.114335

Hadi, R. M. P., Sutikto, T., & Bowo, C. (2019). Soil productivity index based on soil taxonomy and its correlation with coffee productivity in several soil orders. Jurnal Ilmu Tanah Dan Lingkungan, 21(1), 7–12. https://doi.org/10.29244/jitl.21.1.7-12

Hendrayana, H., Widyastuti, M., Riyanto, I. A., Nuha, A., Widasmara, M. Y., Ismayuni, N., & Rachmi, I. N. (2021). Thornthwaite and mather water balance method in indonesian tropical area. IOP Conference Series: Earth and Environmental Science, 851(1). https://doi.org/10.1088/1755-1315/851/1/012011

Horel, Á., & Zsigmond, T. (2023). Plant Growth and Soil Water Content Changes under Different Inter-Row Soil Management Methods in a Sloping Vineyard. Plants, 12(7), 1549. https://doi.org/ 10.3390/plants12071549

IPCC. (2023). Climate Change 2021 – The Physical Science Basis. Cambridge University Press. https://doi.org/10.1017/9781009157896

Johnson, R. (2023). Soil-water retention and its role in crop yield optimization. International Journal of Advanced Chemistry Research, 5(1), 117–120. https://doi.org/10.33545/26646781.2023.v5.i1b.212

Kheyruri, Y., Neshat, A., Sharafati, A., & Hameed, A. S. (2024). Identifying the most effective climate parameters on crop yield in rain-fed agriculture and irrigated farming in Iran. Physics and Chemistry of the Earth, Parts A/B/C, 136, 103744. https://doi.org/10.1016/j.pce.2024.103744

Laimeheriwa, S., Madubun, E. L., & Panggua, M. (2022). Calculation of land water balance and its utilization for determining the growing season in the pulau-pulau aru district, aru islands regency, maluku province. Jurnal Budidaya Pertanian, 18(2). https://doi.org/10.30598/jbdp.2022.18.2.107

Lukman, A. D. (2021). Mapping of Agricultural Land Drought Using the Normalized Difference Drought Index (NDDI) Method in Rambipuji and Wuluhan Districts, Jember [Thesis, Universitas Jember]. https://repository.unej.ac.id/xmlui/handle/123456789/108344?show=full

Madubun, E. L., Ririhena, R. E., Laimeheriwa, S., & Simamora, R. (2024). Analysis of land water balance in various rainfall conditions and its utilization to determine planting patterns of food crops in the eastern part of seram district of seram island. International Journal of Multidisciplinary: Applied Business and Education Research, 5(7), 2365–2375. https://doi.org/10.11594/ijmaber.05.07.03

Mammoliti, E., Fronzi, D., Mancini, A., Valigi, D., & Tazioli, A. (2021). Waterbalance, a webapp for Thornthwaite–Mather water balance computation: Comparison of applications in two European watersheds. Hydrology, 8(1), 1–14. https://doi.org/10.3390/hydrology8010034

Mardawilis, M., Sudira, P. G., Sunarminto, B. H., & Shiddiq, D. (2012). Water balance analysis for the development of food crops in a different climate conditions. https://api.semanticscholar.org /CorpusID:129810279

Musyadik, M., Fathnur, F., Nugroho, W. A., Rusdi, R., Imran, I., Wahid, W., Asmin, A., Sabaruddin, L., Sudia, L. B., & Nur, M. (2023). Spatial analysis of water balance distribution for simulation of timing and patterns of rice and crop planting in the region of type d rainfall in the south konawe regency. Agric, 35(2), 287–300. https://doi.org/10.24246/agric.2023.v35.i2.p287-300

Nangimah, S. L., Laimeheriwa, S., & Tomasoa, R. (2018). The Impact of el nino and la nina phenomena on agricultural land water balance and available growing periods in the waeapo area of buru island. Jurnal Budidaya Pertanian, 14(2), 66–74. https://doi.org/10.30598/jbdp.2018.14.2.66

Nugroho, A. R., Tamagawa, I., Riandraswari, A., & Febrianti, T. (2019). Thornthwaite-mather water balance analysis in tambakbayan watershed, yogyakarta, indonesia. MATEC Web of Conferences, 280, 05007. https://doi.org/10.1051/matecconf/201928005007

Nugroho, R., & Savitri, E. (2017). Carrying capacity of brantas river basin based on evaluation of water management criteria. Prosiding Seminar Nasional Geografi UMS 2017.

Osorio, J., Jeong, J., Bieger, K., & Arnold, J. (2014). Influence of potential evapotranspiration on the water balance of sugarcane fields in maui, hawaii. Journal of Water Resource and Protection, 06(09), 852–868. https://doi.org/10.4236/jwarp.2014.69080

Paredes, P., Pereira, L. S., Almorox, J., & Darouich, H. (2020). Reference grass evapotranspiration with reduced data sets: Parameterization of the FAO Penman-Monteith temperature approach and the Hargeaves-Samani equation using local climatic variables. Agricultural Water Management, 240. https://doi.org/10.1016/j.agwat.2020.106210

Paski, J. A. I., S L Faski, G. I., Handoyo, M. F., & Sekar Pertiwi, D. A. (2018). Land water balance analysis for rice and corn crops in bengkulu city. Jurnal Ilmu Lingkungan, 15(2), 83. https://doi.org/10.14710/jil.15.2.83-89

Pratiwi, A. D., & Nasrul, B. (2022). Analysis of land water balance to set the planting time of upland rice in kampar district. pedontropika : Jurnal Ilmu Tanah Dan Sumber Daya Lahan, 8(2), 61. https://doi.org/10.26418/pedontropika.v8i2.58827

Proutsos, N. D., Tsiros, I. X., Stefanidis, S. P., Tseliou, A., & Evangelinou, E. (2025). Thornthwaite's water balance components in greece with the use of gridded data. HAICTA 2024, 10. https://doi.org/10.3390/proceedings2025117010

Rahmayuni, E., Anwar, S., Nugroho, B., & Indriyati, L. T. (2023). Characteristics of soil chemical properties associated with inceptisols in various land use in jasinga, bogor. Journal Of Tropical Soils, 28(3), 89–97. https://doi.org/10.5400/jts.2023.v28i3.89-97

Ramadhan, M. R., Suharto, E., & Hidayat, M. F. (2022). Water balance analysis of rindu hati sub-basket, bengkulu watershed, bengkulu province (Case Study 2009-2019). Journal of Global Forest and Environmental Science, 2(2). https://www.google.com/url?sa=t&source=web&rct =j&opi=89978449 &url=https://ejournal.unib.ac.id/jhutanlingkungan/article/download/22824/10489&ved=2ahUKEwiKK2w38yMAxW2cGwGHYiaBmsQFnoECCgQAQ&usg=AOvVaw3JRzzmjbdWoOv7ZJX5AsE-

Ritchie, J. T. (1998). Soil water balance and plant water stress (pp. 41–54). https://doi.org/10.1007/978-94-017-3624-4_3

Sabaruddin, L., Arafah, N., Syaf, H., Leomo, S., Corina Rak, T., & La Fua, J. (2021). Analysis of soil water balance to determine planting time of crops on dryland, indonesia. Pakistan Journal of Biological Sciences, 24(2), 241–251. https://doi.org/10.3923/pjbs.2021.241.251

Sirappa, M. P., & Susanto, A. N. (2008). The development of nuts on irrigated lowland rice field at buru island, maluku. Jurnal Budidaya Pertanian, 4(1), 64–72.

Sitanggang, W. R., Amaru, K., Sampurno, R. M., & Lestari, Y. (2022). Water Balance analysis using the thornthwaite-mather method in sweet corn cultivation using an irrigation and mulching system. SNPPM-4, 4, 84–96. https://prosiding.ummetro.ac.id/index.php/snppm

Sofia, D. A., Wibowo, H., & Nursila, N. (2019). Analysis of water balance and shifting planting schedules in the cimandiri irrigation area. JTERA (Jurnal Teknologi Rekayasa), 4(2), 193. https://doi.org/10.31544/jtera.v4.i2.2019.193-202

Soil Survey Staff. (2022). Keys to Soil Taxonomy (Thirteenth Edition). USDA Natural Resources Conservation Service. https://www.nrcs.usda.gov/sites/default/files/2022-09/ Keys-to-Soil-Taxonomy .pdf

Stone, L. F., Carvalho, M. T. de M., da Silva, M. A. S., Calil, F. N., Siqueira, M. M. de B., Moura, T. M., Trogello, E., Machado, P. L. O. de A., Heinemann, A. B., Rangel, A. da C. M., & Madari, B. E. (2025). Intrinsic soil properties shape water availability under changing land-use in contrasting soil textures. Soil Advances, 4, 100082. https://doi.org/10.1016/j.soilad.2025.100082

Sun, B., Yang, Z., Zhao, S., Shi, X., Liu, Y., Ji, G., & Huotari, J. (2023). Water balance analysis of hulun lake, a semi-arid unesco wetland, using multi-source data. Remote Sensing, 15(8), 2028. https://doi.org/10.3390/rs15082028

Susanto, A. N., & Sunarminto, B. H. (2013). Spatial variability of soil inherent fertility status at irrigation rice field in waeapo plain, buru regency. Jurnal Tropical Soils, 18(2), 115–124. https://doi.org/ 10.5400/jts.2013.18.2.115

Syaripah Najihah, T., Hafiz Ibrahim, M., Abd Razak, A., Nulit, R., & Edaroyati Megat Wahab, P. (2019). Effects of water stress on the growth, physiology and biochemical properties of oil palm seedlings. AIMS Agriculture and Food, 4(4), 854–868. https://doi.org/10.3934/agrfood.2019.4.854

Thornthwaite, C. W., & Mather, J. R. (1957). Instruction and tables for computing potential evapotranspiration and the water balance: x (d. b. carter, ed.; 3rd ed.). Publication in Climatology, Laboratory of Climatology.

Todorovic, M. (2016). Soil Water Balance And Irrigation Scheduling. CIHEAM - IAMB.

Tufaila, M., Mpia, L., & Karim, J. (2017). Land water balance analysis of soil types developing in karst areas in parigi district, muna regency, southeast sulawesi. Agritech, 37(2), 215. https://doi.org/10.22146/agritech.16747

Uspessy, J. F., Laimeheriwa, S., & Patty, J. R. (2020). Determination of growing seasons based on land water balance in saumlaki area, yamdena island. Jurnal Budidaya Pertanian, 16(2), 173–179. https://doi.org/10.30598/jbdp.2020.16.2.173

Wadood, A., Hameed, A., Akram, S., & Ghaffar, M. (2024). Unraveling the impact of water deficit stress on nutritional quality and defense response of tomato genotypes. Frontiers in Plant Science, 15. https://doi.org/10.3389/fpls.2024.1403895

Wang, X., Dettman, D. L., Wang, M., Zhang, J., Saito, Y., Quade, J., Feng, S., Liu, J., & Chen, F. (2020). Seasonal wet-dry variability of the Asian monsoon since the middle Pleistocene. Quaternary Science Reviews, 247, 106568. https://doi.org/10.1016/j.quascirev.2020.106568

Wu, J., Zhang, L., Wang, Z., Ge, F., Zhang, H., Yang, J., & Zhang, Y. (2025). Reasonable dry cultivation methods can balance the yield and grain quality of rice. Journal of Integrative Agriculture, 24(3), 1030–1043. https://doi.org/10.1016/j.jia.2023.12.016

Xu, C.-Y., & Singh, V. P. (2005). Evaluation of three complementary relationship evapotranspiration models by water balance approach to estimate actual regional evapotranspiration in different climatic regions. Journal of Hydrology, 308(1–4), 105–121. https://doi.org/10.1016/j.jhydrol.2004.10.024

Yunatas, A., Sabaruddin, L., & Madiki, A. (2021). Land water balance analysis for planning planting times for food crops on dry land in kolaka regency. Berkala Penelitian Agronomi, 8(2), 65. https://doi.org/10.33772/bpa.v8i2.14441

Zhang, Y. wang, Wang, K. bo, Wang, J., Liu, C., & Shangguan, Z. ping. (2021). Changes in soil water holding capacity and water availability following vegetation restoration on the Chinese Loess Plateau. Scientific Reports, 11(1). https://doi.org/10.1038/s41598-021-88914-0

Zheng, H., Bai, J., Niu, P., Peng, T., Jin, Z., Bao, H., Naqvi, S. A. F., & Guan, Y. (2025). Soil water balance in response to rainfall variability over a dammed valley farmland in the Chinese Loess Plateau. Ecological Indicators, 175, 113594. https://doi.org/10.1016/j.ecolind.2025.113594

Zheng, H., Yu, G., Wang, Q., Zhu, X., He, H., Wang, Y., Zhang, J., Li, Y., Zhao, L., Zhao, F., Shi, P., Wang, H., Yan, J., & Zhang, Y. (2016). Spatial variation in annual actual evapotranspiration of terrestrial ecosystems in China: Results from eddy covariance measurements. Journal of Geographical Sciences, 26(10), 1391–1411. https://doi.org/10.1007/s11442-016-1334-8

Zhou, H., & Zhao, W. zhi. (2019). Modeling soil water balance and irrigation strategies in a flood-irrigated wheat-maize rotation system. A case in dry climate, China. Agricultural Water Management, 221, 286–302. https://doi.org/10.1016/j.agwat.2019.05.011

Zike, T. (2019). Review on the effect of moisture or rain fall on crop production. Civil and Environmental Research, 11(02). https://doi.org/10.7176/CER/11-2-01

.