ASIAN JOURNAL OF AGRICULTURE
Volume 10, Number 1, June 2026 E-ISSN: 2580-4537
Pages: 9 https://doi.org/10.13057/asianjagric/g100167

Strategy for determining hotong (*Setaria italica*) planting time based on land water balance study on Yamdena Island, Maluku, Indonesia

JEANNE I. NENDISSA[1,♥], SEMUEL LAIMEHERIWA[1], ROBBY G. RISAMASU[2]
[1]Department of Agrotechnology, Faculty of Agriculture, Universitas Pattimura. Jl. Ir. M. Putuhena, Ambon 97233, Maluku, Indonesia.
Tel./fax.: +62-911-322-489, ♥email: jinendissa@gmail.com
[2]Department of Soil Science, Faculty of Agriculture, Universitas Pattimura. Jl. Ir. M. Putuhena, Ambon 97233, Maluku, Indonesia

Manuscript received: 29 September 2025. Revision accepted: 28 May 2026.

Abstract. *Nendissa JI, Laimeheriwa S, Risamasu RG. 2026. Strategy for determining hotong (*Setaria italica*) planting time based on land water balance study on Yamdena Island, Maluku, Indonesia. Asian J Agric 10 (1): g100167. https://doi.org/10.13057/asianjagric/g100167.* Food security in archipelagic regions still faces significant challenges due to limited food distribution, high dependence on seasonal rainfall, and low diversification of local food sources. One potential commodity that can support food independence in the region is hotong (*Setaria italica*), which is known to have high adaptability to marginal land conditions and limited agricultural inputs. However, hotong productivity on Yamdena Island, Maluku, Indonesia, is still relatively low, mainly due to the lack of determination of planting time that is in accordance with climate dynamics and soil water availability. This study aims to determine the optimal planting period for hotong through a land water balance analysis approach. The data used include rainfall for 30 years (1995-2024), other climate parameters for 15 years (2010-2024), and soil physical properties data, namely field capacity, permanent wilting point, and water holding capacity, plus crop coefficient values. The analysis was carried out by calculating 75% probability rainfall using the rank ordering method, estimating potential evapotranspiration using Cropwat 8.0 software, and integrating all parameters in a land water balance model based on the Thornthwaite and Mather method. Simulation results from 12 planting scenarios indicate that the planting period from December-March to March-June is the safest for hotong cultivation because soil water conditions remain optimal (≥112.5 mm) without deficits. April-July is still possible with small deficits, while May-November is high risk due to large deficits (90-380 mm) and drought during the critical phase. Statistical analysis using one-way ANOVA revealed significant differences in water deficit among planting scenarios ($F=58.47$, $p<0.001$), confirming that early rainy season planting significantly reduces water stress. Therefore, planting at the beginning of the rainy season is recommended to maintain productivity, while serving as a scientific basis for developing an adaptive planting calendar for local food development in archipelagic regions.

Keywords: Food security, hotong, planting period, water balance, Yamdena Island

INTRODUCTION

Food security is a strategic issue in Indonesian agricultural development that faces challenges not only in increasing production but also in equitable access to food, especially in archipelagic regions that have distinctive geographical and ecological characteristics. Archipelagic areas experience logistical constraints due to limited infrastructure and high distribution costs, which often lead to food supply instability. To overcome this food insecurity, the development of local food resources becomes an important strategy in realizing food independence based on regional potential.

Yamdena Island, the largest island in the Tanimbar Islands, Maluku Province, Indonesia, has great potential for the development of local food commodities. However, the agroecosystem of this region is highly influenced by uneven seasonal rainfall patterns. High climate variability and limited soil water reserves are the main obstacles in determining the right planting time. According to Rozaki (2021) and Sairmaly et al. (2024), rainfall fluctuations can cause mismatches between plant growth phases and water availability, thereby reducing agricultural productivity in dryland areas in archipelagic regions.

One potential local food crop on Yamdena Island is hotong (*Setaria italica* L.), which has long been an alternative food source for local communities. This plant has high nutritional value, is drought tolerant, and can grow on marginal land with low water and nutrient inputs. The content of complex carbohydrates, fiber, and protein in its seeds makes hotong important for food diversification and reducing dependence on rice. However, hotong productivity in Indonesia, especially in archipelagic regions, is still low. Research by Mahdya et al. (2022), Fadillatunnisa et al. (2023) and Venkatesh et al. (2024) states that the low yield is due to the lack of application of cultivation strategies adapted to local climate conditions, particularly in determining planting time which is highly dependent on soil water availability.

In dryland agricultural management, a scientific approach that takes into account the balance between rainfall and plant water requirements is very important. One relevant method is land water balance analysis, which assesses soil water dynamics based on rainfall inputs and outputs through evapotranspiration. This approach allows identification of optimal water availability periods and detection of water deficits or surpluses. Yulianti et al. (2023) and Dwiratna et al. (2025) affirm that planting time strategies based on water balance can increase water use efficiency, reduce the risk of crop failure due to drought, and strengthen local food security through adaptive planting planning to climate variability.

Previous studies have focused more on genetic aspects, nutritional content, and hotong growth response to the environment, but agronomic research that emphasizes water requirements and optimal planting time strategies is still limited. Analysis of water requirements for each growth phase is rarely conducted in tropical agroclimatic contexts, whereas inappropriate planting time in dryland often causes water stress that reduces yields. Until now, there has been no comprehensive study that integrates water balance parameters such as potential evapotranspiration, crop coefficient (Kc), and rainfall probability in one analytical system as a basis for establishing a hotong planting calendar.

Furthermore, research on planting scheduling based on water balance for hotong in tropical island ecosystems has practically not been conducted. In fact, this region has high rainfall variability and limited soil water storage capacity. The absence of this information makes farmers still rely on traditional planting patterns that are not always in accordance with local climate dynamics. Therefore, the development of an adaptive planting calendar model based on water balance becomes very important to increase water use efficiency and stability of hotong yields in tropical island environments.

This knowledge gap emphasizes the need for in-depth research to develop a water balance-based approach that is in accordance with the agroclimatic characteristics of the region. This study aims to determine the optimal planting time for hotong plants on Yamdena Island through land water balance analysis that integrates rainfall data, climate parameters, and soil physical properties. This approach allows accurate evaluation of soil water availability in various planting time scenarios to identify the most suitable period for plant growth. This study is the first research that applies water balance methodology comprehensively to hotong in tropical archipelagic ecosystems. The results are expected to be a scientific basis for the preparation of adaptive planting calendars and support sustainable food security strategies in the Maluku Region and eastern Indonesia.

MATERIALS AND METHODS

This study uses biophysical data from Yamdena Island located in the Tanimbar Islands District, Maluku Province, Indonesia. The astronomical position of Yamdena Island is at 7°07' - 8°02' South Latitude and 131°05' - 131°46' East Longitude (Figure 1).

Data collection

This study combines a descriptive approach to explain agroclimatic conditions and land characteristics with a quantitative approach through analysis of rainfall data, potential evapotranspiration, crop coefficient (Kc), and soil water availability. This combination allows determination of hotong planting time based not only on field conditions but also on measured land water balance calculations.

On Yamdena Island, there is only one station that records complete climate time series data: the Saumlaki Meteorological Station. This climate station is considered representative of Yamdena Island as a whole, with an area of approximately 3,100 km², largely flat topography with elevations below 300 m above sea level, and relatively uniform land use. This is consistent with Janis and Robeson (2004), who reported that under relatively homogeneous conditions (uniform land use, non-undulating topography), a single climate station can have a fairly broad representation range, covering 314-7,850 km².

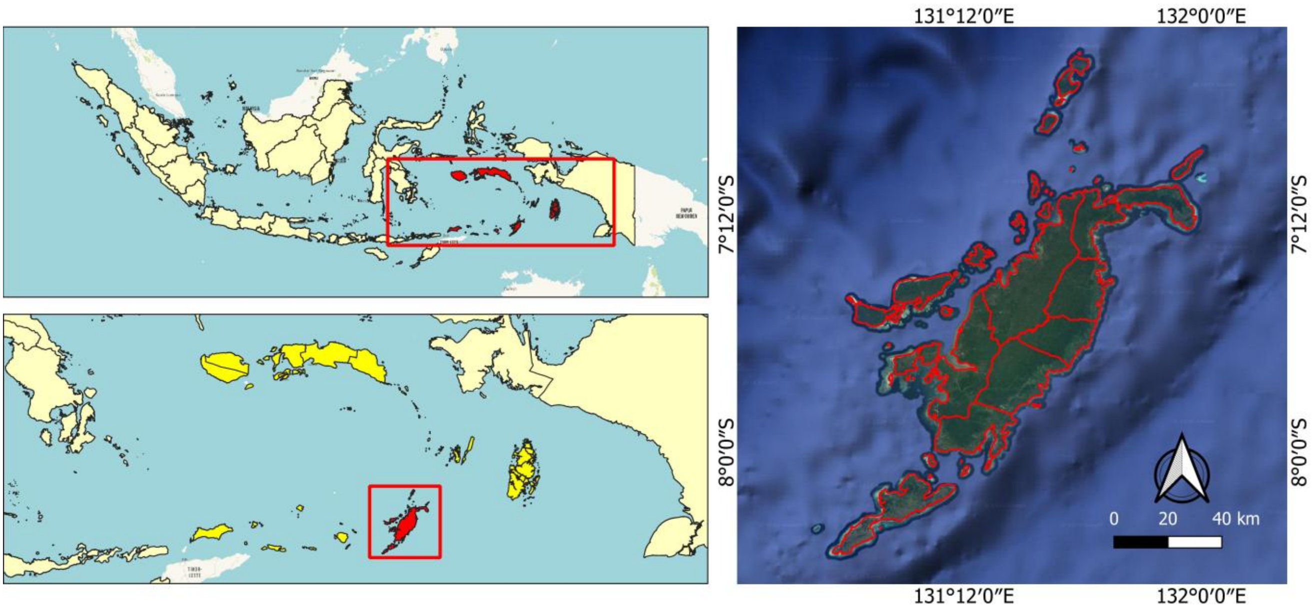

Figure 1. Research location map in Yamdena Island, Maluku, Indonesia

The data used include: (i) rainfall records from Saumlaki Meteorological Station for a period of 30 years, namely 1995-2024. The use of 30-year rainfall data is in accordance with World Meteorological Organization (WMO 2017) recommendations, that climatological data should use a 30-year climate normal so that climate patterns can be described stably and representatively. In addition, other climate data were also utilized, including air temperature, relative humidity, sunshine duration, and wind speed recorded for the last 15 years (2010-2024) to describe climate conditions and calculate potential evapotranspiration. This study also uses supporting data from interviews, field observations, and relevant scientific literature.

Data analysis

Before the analysis was conducted, all climate data were checked for consistency using the Double Mass Curve (DMC) method. Time series data from the Saumlaki Meteorological Station were generally available year-round, with only a small portion of monthly data missing (Xt) and non-sequential. To fill these gaps, the Mean Substitution method was used:

$Xt = \bar{X}$

Where, $\bar{X}$ is the average rainfall value for the same month based on available data (e.g., the average rainfall for January over 29 years).

The data obtained were then analyzed through the following stages:

Calculation of rainfall with 75% exceedance probability (P75)

This was done using the rank ordering method (Rank Ordering Method, Sitorus et al. 2023; Laimeheriwa et al. 2025), namely Fa = 100 m / (N + 1). The following is an example of P75 calculation using the Rank Ordering Method: January rainfall data:

Rainfall data are sorted from largest to smallest value, with sequence number m (1 to 10; total data N = 10). Then the probability of rainfall occurrence is calculated using the formula Fa = 100 m / (N + 1).

Based on the data in Table 1, P75 is between sequence numbers 8 and 9 with rainfall between 110 and 113 mm and Fa 72.7 and 81.8. By interpolating the data, the P75 for January obtained is 110.8 mm; rounded to 111 mm.

Potential evapotranspiration (ETp)

Potential evapotranspiration (ETp) was estimated using the Penman-Monteith method available in Cropwat 8.0 software (Food and Agriculture Organization (FAO) 2009). This program uses input data of maximum and minimum air temperature (°C), relative humidity (%), sunshine duration (hours/day), wind speed (km/day), and astronomical data (latitude and longitude). The output (calculation result) is in the form of daily ETp values which are then multiplied by the number of days each month to obtain monthly ETp values.

Determining crop coefficient values

Crop coefficient (Kc) values for hotong were determined following the methodology of Allen et al. (1998) for small grain cereals, with modifications based on Upadhyaya et al. (2011) for foxtail millet specific characteristics. The Kc values were adjusted according to four distinct growth phases over a 120-day growing period:

Initial phase (0-25 DAP): Germination and early leaf development, characterized by minimal canopy cover and low water demand (Kc = 0.40)

Development phase (25-45 DAP): Rapid vegetative growth with increasing leaf area index, transitioning from Kc = 0.40 to 1.10

Mid-season phase (45-90 DAP): Maximum canopy development, flowering, and grain filling, representing peak water demand (Kc = 0.70-1.10)

Late season phase (90-120 DAP): Physiological maturity and senescence, with declining water requirements (Kc = 0.50)

Monthly Kc values were calculated by averaging the daily Kc across each 30-day period, considering the proportional duration of each growth phase within that month. This approach allows integration of Kc values with monthly rainfall and ETp data in the water balance model (Table 2)

Establishing soil parameter values

Determine the Permanent Wilting Point (PWP), Field Capacity (FC), Water Holding Capacity (WHC), and maximum root depth of hotong based on relevant scientific references, as shown in Table 3. The FC, PWP, and WHC values were determined using a soil texture-based pedotransfer approach, which has been widely used in water balance modeling for areas with limited primary data.

Table 1. Example of P75 calculation for January using the Rank Ordering Method

Rainfall time series data										
Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2012**	**2022**	**2023**	**2024**
Rainfall (mm)	285	167	198	290	268	105	110	300	289	113
Calculation of rainfall with 75% eceedance probability (P75)										
Sequence number (m)	1	2	3	4	5	6	7	**8**	**9**	10
Rainfall (mm)	300	290	289	285	268	198	167	**113**	**110**	105
Probability, Fa (%)	9.1	18.2	27.3	36.4	45.5	54.5	63.6	**72.7**	**81.8**	90.9

Table 2. Kc values per hotong development phase

Development phase	Age (DAP)	Main activity	Kc value
Initial	0-25	Germination & early leaf formation	0.40
Development (vegetative)	25-45	Leaf & stem growth	0.40-1.10
Flowering-Grain filling	45-90	Panicle & seed formation	0.0-1.10
Maturation	90-120	Final filling & seed ripening until harvest	0.50

Note: DAP: Days after planting

Table 3. FC, PWP, and WHC values at various soil textures

Soil texture	mm water per m soil depth		
	FC	PWP	WHC
Sand	150	70	80
Sandy Loam	200	90	110
Loam	310	140	170
Clay Loam	360	170	190
Silty Clay	400	190	210
Clay	430	210	220

Source: Uspessy et al. (2020) and Penggua (2024)

The determination of FC, PWP, and WHC values for the research location is adjusted to the dominant soil texture. Meanwhile, the maximum root depth of hotong was obtained from field surveys and relevant scientific references. This model uses several key assumptions: the soil is assumed to be homogeneous at a depth of 0-50 cm and has no impermeable layer; microtextural variations are ignored so that water capacity represents average conditions; root depth is assumed to remain constant throughout the season; and drainage is assumed to be good. These assumptions are appropriate for limited data, although laboratory analysis and dynamic root modeling will improve accuracy.

Calculation of hotong land water balance

Calculation of hotong land water balance uses a bookkeeping system developed by Thornthwaite and Mather (1957) which is modified, namely ETp values are calculated using the Penman-Monteith method and the addition of Kc values as input. The calculation stages begin with the preparation of a monthly water balance table (12 planting time scenarios; January to December) containing P75, ETp, and Kc data. Plant water requirements are calculated as ETc = Kc × ETp. Then the difference P75 - ETc is calculated; negative results are accumulated as APWL (potentially lost water). Determination of soil parameters such as FC, PWP, and WHC. Soil water content (SWC) is calculated based on WHC and APWL, and is used to obtain changes in soil water content (dSWC). Actual evapotranspiration (ETa) is determined according to P and ETc conditions, with a maximum limit of ETa = ETc. Finally, water deficit (D = ETc - ETa) and water surplus (S = P75 - ETc - dSWC) are calculated.

Determination of effective planting time

Determination of effective planting time for hotong on Yamdena Island is based on simulation of 12 planting time scenarios. The selected planting time is one that meets three criteria, namely: (i) absence of water deficit during the growth period, especially in the critical phase in the 2nd and 3rd months, (ii) soil water availability at optimum conditions, and (iii) controlled water surplus.

Statistical analysis

Water deficit data from all 12 planting scenarios were subjected to one-way Analysis of Variance (ANOVA) to test for significant differences among planting periods. When significant differences were detected ($p<0.05$), Duncan's Multiple Range Test was performed as a post-hoc analysis to identify homogeneous groups. Statistical analyses were conducted using SPSS version 25.0 software.

RESULTS AND DISCUSSION

Regional climate conditions

Analysis of rainfall data over a three-decade period (1995-2024) on Yamdena Island shows significant fluctuations from year to year. This variation is reflected in annual rainfall records, where 1997 was recorded as the period with the lowest rainfall, reaching only 1,169 mm, while 2010 was the highest with 3,447 mm. In general, the average annual rainfall in this region is around 2,032 mm, a figure that illustrates that Yamdena is a region with relatively high water availability, although its distribution is not always evenly distributed over time (Figure 2).

If examined in more detail based on monthly distribution, there is a sharp difference between the rainy season and the dry season. The highest average monthly rainfall occurs in May with an accumulation of 363 mm. Conversely, September shows very dry conditions, with an average of only 14 mm. This seasonal pattern shows a concentration of rainfall in certain periods of the year, thus posing unique challenges for the agricultural sector which is highly dependent on water availability. Visually, the dynamics of average monthly rainfall can be observed in Figure 3, which shows a clear contrast between the peak rainy season and the long dry period.

Based on average monthly rainfall data and referring to the Oldeman (1975) climate classification for food crop development, Yamdena Island belongs to agroclimatic zone C3. This zone is characterized by six consecutive wet months (≥200 mm) in the December to May period, and five consecutive dry months (<100 mm) in July to November. Under these conditions, the C3 agroclimatic zone on Yamdena Island has a plant growing period of about seven months, from December to June.

The average daily temperature at the research location ranges from 26.1-28.6°C with an annual value of 27.4°C. Relative humidity is positively related to rainfall with an annual average of 81%, lowest 77% (August) and highest 86% (March). Sunshine duration varies from 52% (January) when rainfall is high to 91% (September) when rainfall is minimal. In the rainy season the average sunshine is 58%, while in the dry season 80%. The average wind speed on Yamdena Island is 4.0-8.7 knots, influenced by monsoon winds and local geographical and topographical conditions.

Land water balance of hotong plants

Water availability in tropical regions is highly influenced by rainfall, while plant water requirements are determined by potential evapotranspiration and soil water storage capacity. To relate these three factors, land water balance calculations are used which can show periods of water deficit or surplus and periodic fluctuations in soil water content. This information is important for agricultural management, such as determining planting time and patterns, irrigation needs, and adaptation strategies to local climate variations (Wanniarachchi and Sarukkalige 2022; Etedali et al. 2025).

In this study, the main components used in calculating land water balance for hotong plants on Yamdena Island are rainfall with 75% exceedance probability (P75) and crop evapotranspiration (ETc). ETc calculation is done by multiplying the crop coefficient (Kc) by potential evapotranspiration (ETp), so the formula ETc = Kc × ETp is obtained. In addition, land water balance calculation also requires supporting data in the form of permanent wilting point (PWP) values, field capacity (FC), water availability (WA), and maximum root depth of hotong plants.

75% probability rainfall and potential evapotranspiration

In dryland farming systems, water only comes from rainfall. However, due to its fluctuating and unpredictable nature, the use of monthly averages often does not reflect actual conditions. Therefore, agroclimatic analysis and land water balance calculations are more appropriately done using rainfall with 75% exceedance probability, so that drought risk can be minimized and agricultural planning becomes more targeted (Singh et al. 2023; Lai et al. 2025).

Potential evapotranspiration is the amount of water that will be lost through evaporation and plant transpiration if water is sufficiently available, influenced by climate factors such as temperature, solar radiation, humidity, wind, and sunshine duration. ETp is used in agriculture to estimate plant water requirements, plan irrigation, calculate land water balance, and manage water supply so that optimal plant growth and risk of water deficit or excess can be minimized (Zheng et al. 2024; Hasan et al. 2025).

The results of rainfall analysis with 75% exceedance probability using the Rank Ordering Method. Then, the potential evapotranspiration calculations through Cropwat 8.0 Program on Yamdena Island are presented in Table 4.

Table 3 shows that annual rainfall with 75% probability reaches 1,161 mm, but its distribution is not evenly distributed throughout the year. Relatively high rainfall occurs in January and May (≥200 mm), while in the August to November period there is almost no rain (0-8 mm), potentially causing drought. On the other hand, ETp values tend to be stable throughout the year with a total of 1,673 mm/year and monthly averages ranging from 130-157 mm, indicating fairly constant water requirements. The mismatch between rainfall and ETp, especially in the dry season, confirms the need for water balance analysis to determine optimal hotong planting time.

Table 4. 75% probability rainfall (P75) and potential evapotranspiration (ETp) of Yamdena Island, Maluku, Indonesia

Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Agt	Sep	Oct	Nov	Des	Annually
P75 (mm)	210	169	151	134	212	94	42	7	0	0	8	134	1161
ETp (mm)	137	131	138	132	137	128	130	143	147	157	152	141	1673

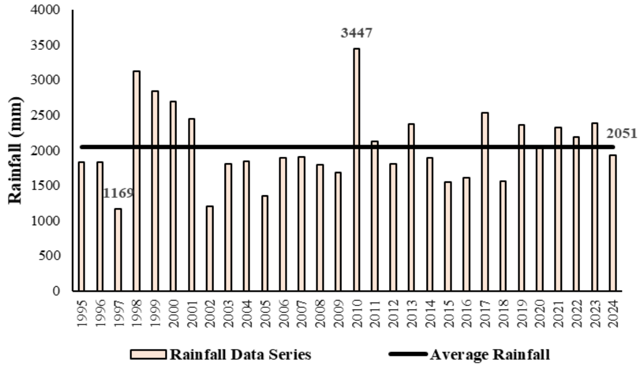

Figure 2. Distribution of annual rainfall on Yamdena Island, Maluku, Indonesia

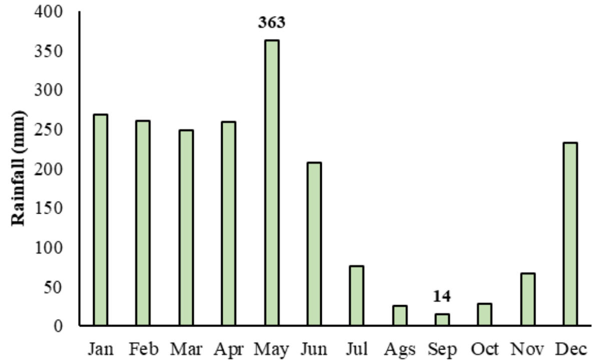

Figure 3. Monthly rainfall on Yamdena Island, Maluku, Indonesia

Hotong crop coefficient

Crop coefficient is a factor used to convert ETp to ETc at various stages of plant growth. Kc values vary depending on plant type, growth phase, and environmental conditions. Kc is used in irrigation planning and land water balance calculations to ensure plants receive water according to needs, so that optimal growth and risk of water deficit can be minimized (Nagy et al. 2024; Tegegne et al. 2025).

Referring to Allen et al. (1998) and Upadhyaya et al. (2011), Kc values for hotong (*S. italica*) local varieties on Yamdena Island with a four-month harvest age at each development phase can be modified in the form of monthly values as follows:

Monthly Kc for hotong:

Month 1: Initial phase (0-15 DAP) → Early development phase (16-30 DAP), Kc ~ 0.55

Month 2: Late development phase → Mid-season phase (41-60 DAP), Kc ~ 1.05

Month 3: Grain filling phase (61-80 DAP) → Early maturation phase (81-90 DAP), Kc ~ 0.85

Month 4: Physiological maturity phase until harvest (91-120 DAP), Kc ~ 0.50

Hotong Kc values vary according to growth phase. In the first month, when plants are in the initial to early development phase (0-30 DAP), Kc values are relatively low around 0.55. Entering the second month, when plants experience late development to maximum growth phase (41-60 DAP), Kc values increase significantly to 1.05, reflecting the highest water requirement. Furthermore, in the third month which includes the grain filling phase to early maturation (61-90 DAP), Kc values decrease to around 0.85. In the fourth month, when plants enter the physiological maturity phase until harvest (91-120 DAP), Kc values return to low at around 0.50. This pattern shows that hotong water requirements are most critical during the mid-growth phase (2nd and 3rd months after planting), so water management during this period becomes very important to support productivity.

Biophysical parameters of land water balance

Based on field survey results combined with literature review, including Tomasoa et al. (2022), Jannah et al. (2024), and Osok et al. (2024), soil-plant biophysical parameters were established for use in land water balance calculations for hotong. Osok et al. (2024) reported that the dominant soil type on Yamdena Island is rendzina which is mostly loam textured. The effective depth of this soil varies from <20 cm to 90 cm, which is utilized by local communities for annual crop cultivation. Referring to Table 2 data above, the FC, PWP, and WHC values on Yamdena Island are set at 310, 140, and 170 mm/m soil depth, respectively.

Research results by Tomasoa et al. (2022) and Jannah et al. (2024), found that the maximum root depth of hotong varies from 30 to 50 cm. Using effective hotong root depth ≤50 cm, PWP value is obtained at 70 mm, FC at 155 mm, and WHC at 85 mm. The determination of these parameters is important because these three components determine the amount of soil water reserves that can be utilized by plants throughout the growth phase, while serving as a basis in water availability analysis and identification of deficit risk periods.

Hotong plant land water balance scenarios

Water balance simulation results (Table 5) show that the January-April, February-May, March-June, and December-March planting period scenarios are relatively safe periods for hotong cultivation. In these scenarios there is no water deficit, soil water content is in optimum condition (≥112.5 mm), and the critical growth phase is free from water shortage risk.

This pattern shows that the success rate of hotong cultivation is higher if planting is done at the beginning of the rainy season (December-March), while delaying to mid or late rainy season carries a high risk of causing water stress and decreased productivity. These findings are in line with research results on various dryland crops. Mondo et al. (2024) reported that adjustment of yam planting calendars in Central Africa based on rainfall distribution was able to increase productivity while reducing water deficit risk, and proved effective as a climate adaptation strategy. Similarly, Tang et al. (2024) showed that earlier corn planting at the beginning of the rainy season keeps soil moisture stable, reduces water stress risk, and increases water use efficiency compared to delayed planting.

The April-July scenario is also still feasible, although there is a small deficit of 3 mm in the final growth phase in July. Conversely, planting periods starting from May to November show quite large limitations, with accumulated water deficits between 90-380 mm, soil water content far below optimum conditions (70-86 mm), and significant deficits in the critical phase, especially during July-October. This pattern shows that the success rate of hotong cultivation is higher if planting is done at the beginning of the rainy season (December-March), while delaying to mid or late rainy season carries a high risk of causing water stress and decreased productivity.

Effective planting time for hotong plants on Yamdena Island, Maluku, Indonesia

Based on land water balance calculations for hotong on Yamdena Island, optimal planting periods can be determined by considering three main criteria: (i) absence of water deficit during the growth period, (ii) soil water availability at optimum conditions (≥112.5 mm), and (iii) controlled water surplus so as not to cause risks of waterlogging, nutrient leaching, or erosion.

Of the 12 scenarios tested, the December-March scenario ranks best because all indicators are met where there is no water deficit, soil moisture remains optimum, and water surplus is in the low to medium range (38-82 mm). These conditions provide adequate water for plants without causing negative impacts from excess water. The March-June scenario is also very promising because there is no water deficit, soil water content is stable at optimum level, and surplus is relatively low (30-95 mm). Another alternative that is still possible is April-July, although there is a small deficit (3 mm) at the end of the planting period, as well as January-April which has the potential to produce high water surplus in January (113 mm) so it requires good drainage management. Meanwhile, the January-April and February-May scenarios are very risky for high water surplus which has the potential for waterlogging in planting areas that negatively impacts plant growth; where at the beginning of planting in January water surplus is 113 mm and at the end of planting in May it is 144 mm.

Xia et al. (2024) and Zhang et al. (2025) reported that waterlogging in hotong plants causes hypoxic conditions that inhibit root respiration, reduce energy production, and disrupt ion absorption. The availability of nutrients such as N, K, and Fe decreases, while toxic ion accumulation can occur, resulting in chlorosis and decreased photosynthesis. Increased ethylene sometimes triggers aerenchyma formation as an adaptation mechanism, although its effectiveness depends on genotype. Waterlogging also causes oxidative stress with increased MDA and changes in antioxidant enzyme activity, and in the reproductive phase can reduce seed formation and filling, so harvest yields decrease in various species, including *S. italica*.

Conversely, scenarios with planting starting from May to November should be avoided because they are characterized by large water deficits and soil moisture conditions far from optimum. This water shortage condition will negatively impact plant physiology. Gao et al. (2023) and Chang et al. (2024) reported that water shortage in hotong plants causes stomatal closure which reduces carbon dioxide assimilation and photosynthesis, so growth and yield decrease. Decreased leaf water pressure triggers wilting and inhibits tissue expansion. Plants adapt by accumulating osmolytes such as proline and soluble sugars to maintain turgor. Antioxidant enzyme activity increases to suppress oxidative stress, although lipid peroxidation can still occur. In addition, genes related to ABA and detoxification are activated, while drought during seed formation phase reduces seed number and content. This condition is also reported by Zhao et al. (2025), physiologically, water shortage in hotong plants reduces production through several interrelated mechanisms. Stomatal closure and decreased photosynthesis limit dry matter formation, so biomass accumulation and vegetative growth decrease. Prolonged water stress also inhibits seed formation and filling due to disruption of photoassimilate supply during the reproductive phase. Although plants perform osmotic adjustment and increase antioxidant enzyme activity to maintain cell function, these responses are only temporary. As a result, physiological efficiency decreases, panicle number and seed weight decrease, and total harvest yield becomes lower.

Thus, the results of this study confirm that the most suitable planting period for hotong on Yamdena Island is December-March and March-June, while April-July and January-April can be alternative choices if accompanied by adequate water management strategies. Meanwhile, planting periods starting from May to November are not recommended due to high water deficits and low soil water content.

Table 5. Summary of hotong plant land water balance calculation scenarios on Yamdena Island, Maluku, Indonesia

Scenario	Planting period	Soil water conditions		
		Deficit (mm)	**Surplus (mm)**	**Soil water content (mm)**
1	January (Jan)-April (Apr)	No deficit	Jan: 113, Feb: 31, Mar: 34, Apr: 68	Jan-April: 155
2	February (Feb)-May	No deficit	Feb: 97, Mar: 6, Apr: 22, May: 144	Feb-May: 155
3	March (Mar)-June (Jun)	No deficit	Mar: 75, Apr: 1, May: 90, Jun: 30	Mar, May, June: 155, Apr: 149
4	April-July (Jul)	July: 3	Apr: 61, May: 68, Jun: 3	Apr, May: 155, Jun: 137, Jul: 117
5	May-Agustus (Ags)	Jun: 1, Jul: 39, Ags: 55	May: 137	May: 155, Jun: 116, Jul: 86, Ags: 76
6	June-September (Sep)	Jul: 29, Ags: 99, Sep: 72	Jun: 24	Jun: 155, Jul: 89, Ags: 73, Sep: 71
7	July-October (Oct)	Ags: 96, Sep: 120, Oct: 78	Jul: 3	Jul: 123, Ags: 76, Sep: 71, Okt: 70
8	August-November (Nov)	Aug: 41, Sep: 139, Oct: 132, Nov: 68	No surplus	Aug: 86, Sep: 71, Oct, Nov: 70
9	September-December (Dec)	Sep: 77, Oct: 163, Nov: 121	No surplus	Sep: 72, Oct, Nov: 70, Dec: 134
10	October-January	Oct: 85, Nov: 152	Jan: 71	Oct, Nov: 70, Dec: 84, Jan: 155
11	November-February	Nov: 76, Dec: 14	Jan: 9, Feb: 104	Nov, Dec: 70, Jan: 155, Feb: 155
12	December-March	No deficit	Jan: 38, Feb: 58, Mar: 82	Dec: 126, Jan-Mar: 155

Note: Optimum soil water content: SWCopt = SWC≥PWP+0.5 x WHC (Las 1992; Lesilolo et al. 2024). Hotong SWCopt≥112.5 mm. Until now there is no single standard threshold for categorizing monthly water surplus. According to land water balance calculation results in this study where water surplus ranges from 1 to 144 mm, water surplus can be categorized as low <50 mm/month; medium 50-100 mm/month; high >100 mm/month

Study limitations and future research

This study represents an initial modeling effort to determine the optimal planting time for hotong in a data-constrained area. However, several limitations should be noted. Crop and soil parameters, including crop coefficient (Kc), soil water capacity (FC, PWP, and WHC), and root depth, are derived from literature rather than local measurements, and therefore may not capture site-specific variability. The model also assumes homogeneous soil, constant root depth, and stationary climate conditions without considering seasonal climate variability (e.g., ENSO) or climate change projections. Certain hydrological processes, such as runoff, dynamic infiltration, and effective rainfall, have not been incorporated, which could impact the accuracy of the water balance. Furthermore, the model-based analysis has not been validated with field data and does not include formal sensitivity or uncertainty analyses.

Future research needs to collect high-resolution agro-meteorological data and conduct local calibrations for crop and soil parameters. Field trials are essential to validate the simulation results. The development of a more comprehensive hydrological scheme and sensitivity and uncertainty analyses (e.g., Monte Carlo simulations) will enhance model robustness. Integration of climate projections and ENSO signals is essential for formulating adaptive cropping calendars. Furthermore, participatory approaches with local farmers, socioeconomic feasibility assessments, detailed spatial mapping of soils and topography, and studies of seed systems and labor calendars will strengthen the practical relevance and likelihood of adoption of recommendations at the field level.

In conclusion, this study demonstrates that the optimal planting periods for hotong on Yamdena Island are December-March and March-June, as these periods ensure no water deficit and maintain optimum soil moisture conditions, with only low to moderate water surplus. Statistical analysis ($F=58.47$, $p<0.001$) confirms that planting at the onset of the rainy season significantly reduces water stress and supports crop productivity.

April-July and January-April may be considered as alternative planting windows with appropriate water and drainage management, while planting from May to November should be avoided due to high water deficits and unfavorable soil moisture conditions. Accordingly, adaptive strategies such as improved drainage, mulching, soil moisture conservation, and the use of stress-tolerant varieties are recommended to enhance resilience under variable climatic conditions.

However, this study is subject to several limitations, including reliance on secondary data, literature-based crop and soil parameters, and simplifying assumptions such as homogeneous soil conditions and static root depth. The model also excludes dynamic hydrological processes, climate variability (e.g., ENSO), and lacks field validation.

Future research should prioritize field-based validation, local parameter calibration, and integration of climate variability and projection scenarios. Expanding the model to include hydrological complexity, sensitivity and uncertainty analyses, and incorporating socioeconomic and participatory approaches will further strengthen the applicability of adaptive planting calendar strategies in archipelagic agroecosystems.

REFERENCES

Allen RG, Pereira LS, Raes D, Smith M. 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements (FAO Irrigation and Drainage Paper No. 56). Food and Agriculture Organization of the United Nations, Rome.

Chang X, Zhang S, Cao C, Zhou J, Wang X, Zhang D, Xiang J. 2024. Transcriptome analysis and characteristics of drought resistance-related genes in four varieties of foxtail millet (*Setaria italica*). Heliyon 10 (18): e38083. https://doi.org/10.1016/j.heliyon.2024.e38083.

Dwiratna S, Ayu YL, Asdak C, Pithaloka NA. 2025. Water balance analysis using the Thornthwaite-Mather method as a basis for cropping pattern development in dry land. Jurnal Teknik Pertanian Lampung 14 (2): 547-559. https://doi.org/10.23960/jtep-l.v14i2.547-559.

Etedali HR, Gorginpaveh F, Elbeltagi A, Abdollahzadeh M, Collins B, Salem A. 2025. Estimation of actual evapotranspiration and irrigation requirement: Comparison of AquaCrop and CROPWAT models. Sci Rep 15: 15759. https://doi.org/10.1038/s41598-025-84986-4.

Fadillatunnisa F, Indradewa D, Putra ETS. 2023. Effects of husk charcoal and watering on the biochemical and physiological properties of coix millet (*Setaria italica* L.) during vegetative phase. Ilmu Pertanian 8 (2): 113-120. https://doi.org/10.22146/jip.79244.

Food and Agriculture Organization (FAO). 2009. CROPWAT 8.0 for Windows: Crop Water Requirements and Irrigation Planning Software [Computer software]. Food and Agriculture Organization of the United Nations, Rome. https://www.fao.org/land-water/databases-and-software/cropwat.

Gao H, Ge W, Bai L, Zhang T, Zhao L, Li J, Shen J, Xu N, Zhang H, Wang G, Lin X. 2023. Proteomic analysis of leaves and roots during drought stress and recovery in *Setaria italica* L. Front Plant Sci 14: 1240164. https://doi.org/10.3389/fpls.2023.1240164.

Hasan RH, Febrianti E, Hijria H, Ulfa NI, Awaluddin A, Nuraida W. 2025. Waktu tanam berbasis iklim dan kondisi tanah lahan penanaman padi gogo wilayah Laeya, Kabupaten Konawe Selatan Periode El Nino. Agroteknika 8 (1): 78-93. https://doi.org/10.55043/agroteknika.v8i1.453. [Indonesian]

Janis MJ, Robeson SM. 2004. Determining the spatial representativeness of air-temperature records using variogram-nugget time series. Phys Geogr 25 (6): 513-530. https://doi:10.2747/0272-3646.25.6.513.

Jannah RM, Silva CB, Gomes-Junior FG, Marcos-Filho J. 2024. Digital phenotyping for robust seed variability assessment of foxtail millet (*Setaria italica*). J Seed Sci 46: e202446028. https://doi.org/10.1590/2317-1545v44268594.

Lai X, An D, Shen Y. 2025. Effects of rainfall variability on productivity and profitability in the intensified annual forage-winter wheat cropping systems on the Loess Plateau of China. Crop Sci 65 (2): e70006. https://doi.org/10.1002/csc2.70006.

Laimeheriwa S, Risamasu, RG, Osok RM, Jambormias E, Parera DF. 2025. Analysis of soil water balance to determine the available growing period in Nusalaut Island, Maluku Province. IOP Conf Ser Earth Environ Sci 1527 (1): 012001. https://doi:10.1088/1755-1315/1527/1/012001.

Las I. 1992. Pewilayahan Komoditi Pertanian Berdasarkan Model Iklim Kabupaten Sikka dan Kabupaten Ende, Nusa Tenggara Timur. [Dissertation]. Graduate School IPB, Bogor. [Indonesian]

Lesilolo MK, Laimeheriwa S, Madubun EL, Wutres I. 2024. Anomali iklim El Nino dan dampaknya terhadap neraca air lahan jagung di Pulau Babar, Kabupaten Maluku Barat Daya. Agrologia 13 (1): 54-63. https://doi.org/10.30598/agrologia.v13i1.12487. [Indonesian]

Mahdya AS, Farahdillah R, Kadapi M, Nurmala T. 2024. Growth and yield response of Watani Wado job's tears (*Coix lacrymajobi* L.) to the application frequency of phosphate fertilizer and paclobutrazol in different growing seasons. Jurnal Kultivasi 23 (1): 52-60. https://doi.org/10.24198/kultivasi.v23i1.47355.

Mondo JM, Chuma GB, Matiti HM, Kihye JB, Bagula EM, Karume K, Kahindo C, Egeru A, Majaliwa JGM, Agre PA, Adebola PA, Asfaw A. 2024. Crop calendar optimization for climate change adaptation in yam farming in South-Kivu, Democratic Republic of the Congo. PLOS One 19 (2): e0309775. https://doi.org/10.1371/journal.pone.0309775.

Nagy A, Kiss NE, Buday-Bódi E, Magyar T, Cavazza F, Gentile SL, Abdullah H, Tamás J, Fehér ZZ. 2024. Precise crop coefficient estimation for maize cultivation using high-resolution satellite images. Plants 13 (9): 1212. https://doi.org/10.3390/plants13091212.

Oldeman LR. 1975. An Agroclimatic Map of Java. Central Research Institute for Agriculture, Bogor.

Osok RM, Siahaya AW, Laimeheriwa S. 2024. Characteristics of Land Resources and Agricultural Systems in the Districts of South Tanimbar and North Tanimbar, Tanimbar Islands Regency. Basic Research Report. Pattimura University, Ambon.

Penggua M. 2024. Analysis of extreme El Niño Rainfall and Its Impact on Soil Water Content and Planting Season Shift in Two Regions with Local and Equatorial Rainfall Patterns in Maluku Province. [Thesis]. Graduate Program, Unpatti, Ambon.

Rozaki Z. 2021. Food security challenges and opportunities in indonesia post COVID-19. Adv Food Secur Sustain 6: 119-168. https://doi.org/10.1016/bs.af2s.2021.07.002.

Sairmaly FA, Laratmase P, Feninlambir M, Batmomolin Y. 2024. Analysis of potential sectors in Tanimbar Islands Regency. J Markcount Finance 2 (1): 82-97. https://doi.org/10.70177/jmf.v2i1.621.

Singh D, Lawrence K, Marker S, Bhattacharjee I, Lawrence R, Choudhary R, Ercisli S, Karunakaran R. 2023. Rainfed assessment of foxtail millet (*Setaria italica* L. beauv) germplasms through genotyping and principal component analysis. Front Plant Sci 14: 1017652. https://doi.org/10.3389/fpls.2023.1017652.

Sitorus BWM, Laimeheriwa S, Madubun EL. 2023. Analisis kondisi iklim dan pemanfaatannya untuk penetapan musim tanam dan pola tanam di daerah Taniwel Kabupaten Seram Bagian Barat. Jurnal Pertanian Kepulauan 7 (1): 9-22. https://doi.org/10.30598/jpk.2023.7.1.9. [Indonesian]

Tang H, Xie X, Zhang L, Liu C. 2024. Assessing the influence of planting dates on sustainable maize production under drought stress conditions. Sustainability 16 (11): 4571. https://doi.org/10.3390/su16114571.

Tegegne D, Schmitter P, Worqlul AW, Lefore N. 2025. Estimating crop coefficients for vegetable production and agricultural water management under climate change in sub-humid tropics. Front Water 7: 1355154. https://doi.org/10.3389/frwa.2025.1355154.

Thornthwaite CW, Mather JP. 1957. Instruction and Tables for Computing Potential Evapotranspiration and the Water Balance. Drexel Institute of Climatology, New Jersey.

Tomasoa RS, Patty JR, Nendissa JI. 2022. Effect of Top G2 liquid organic fertilizer and application time frequency on growth and yield of hotong (*Setaria italica* L). Agrologia 11 (2): 186-194. https://doi.org/10.30598/AJIBT.V11I2.1635.

Upadhyaya HD, Ravishankar CR, Narasimhudu Y, Sarma NDRK, Singh SK, Varshney SK, Reddy VG, Singh S, Parzies HK, Dwivedi SL, Nadaf H, Sahrawat KL, Gowda CLL. 2011. Identification of trait-specific germplasm and developing a mini core collection for efficient use of foxtail millet genetic resources in crop improvement. Field Crop Res 124 (3): 459-467. https://doi.org/10.1016/j.fcr.2011.08.004.

Uspessy JF, Laimeheriwa S, Patty JR. 2020. Penentuan musim tanam berdasarkan perhitungan neraca air lahan di Daerah Saumlaki, Pulau Yamdena. Jurnal Budidaya Pertanian 16 (2): 173-179. https://doi.org/10.30598/jbdp.2020.16.2.173. [Indonesian]

Venkatesh T, Ashokkumar K, Gopalakrishnan G, Bhaalaaji DS, Ajaikumar T, Sundar SN, Vellaikumar S. 2024. Millets: Exploring their genetic diversity, nutritional composition, and pharmacological potentials. Food Human 2: 100457. https://doi.org/10.1016/j.foohum.2024.100457.

Wanniarachchi S, Sarukkalige R. 2022. A review on evapotranspiration estimation in agricultural water management: Past, present, and future. Hydrology 9 (7): 123. https://doi.org/10.3390/hydrology9070123.

World Meteorological Organization (WMO). 2017. WMO Guidelines on the Calculation of Climate Normals (WMO-No. 1203). World Meteorological Organization, Geneva. https://library.wmo.int/records/item/55797-wmo-guidelines-on-the-calculation-of-climate-normals.

Xia X, Fu X, Zhao Y, Cui J, Xiao N, Wang J, Lu Y, Huang M, Chu C, Zhang J, Yang M, Li S, Liu J. 2024. SiRAP2-12, a positive regulatory factor, effectively improves the waterlogging tolerance of foxtail millet (*Setaria italica*). Phyton - Intl J Exp Bot 93 (3): 445-465. https://doi.org/10.32604/phyton.2024.048273.

Yulianti V, Impron, Pramudia A. 2023. The optimum planting time and cropping pattern of potatoes and other horticultural commodities based on water balance in Solok, Indonesia. Agromet 37 (1): 1-11. https://doi.org/10.29244/j.agromet.37.1.1-11.

Zhang Y, Chen X, Geng S, Zhang X. 2025. A review of soil waterlogging impacts, mechanisms, and adaptive strategies. Front Plant Sci 16: 1545912. https://doi.org/10.3389/fpls.2025.1545912.

Zhao Y, Liu J, Kuerban Z, Wang H, Yang B, Wang HJ, Hu X, Bhanbhro N, Feng G. 2025. Drought tolerance evaluation and classification of foxtail millet (*Setaria italica*) germplasm under different water stress conditions. Front Plant Sci 16: 1547112. https://doi.org/10.3389/fpls.2025.1547112.

Zheng C, Jia L, Menenti M, Hu G, Lu J, Chen Q, Jiang M, Mancini M, Corbari C. 2024. Integrating hydrologic modeling and satellite remote sensing to assess the performance of sprinkler irrigation. Geo-Spatial Inform Sci 27 (3): 934-952. https://doi.org/10.1080/10095020.2024.2344615.