Morpho-physiological traits and yield quality for cassava genotypes planted under drought during canopy establishment (#116450)

First submission

Guidance from your Editor

Please submit by **11 May 2025** for the benefit of the authors (and your token reward) .

Structure and Criteria
Please read the 'Structure and Criteria' page for guidance.

Author notes
Have you read the author notes on the guidance page?

Raw data check
Review the raw data.

Image check
Check that figures and images have not been inappropriately manipulated.

If this article is published your review will be made public. You can choose whether to sign your review. If uploading a PDF please remove any identifiable information (if you want to remain anonymous).

Files
Download and review all files from the materials page.

4 Figure file(s)
7 Table file(s)
1 Raw data file(s)

Structure and Criteria

Structure your review

The review form is divided into 5 sections. Please consider these when composing your review:

1. **BASIC REPORTING**
2. **EXPERIMENTAL DESIGN**
3. **VALIDITY OF THE FINDINGS**
4. General comments
5. Confidential notes to the editor

You can also annotate this PDF and upload it as part of your review

When ready submit online.

Editorial Criteria

Use these criteria points to structure your review. The full detailed editorial criteria is on your guidance page.

BASIC REPORTING

- Clear, unambiguous, professional English language used throughout.
- Intro & background to show context. Literature well referenced & relevant.
- Structure conforms to PeerJ standards, discipline norm, or improved for clarity.
- Figures are relevant, high quality, well labelled & described.
- Raw data supplied (see PeerJ policy).

EXPERIMENTAL DESIGN

- Original primary research within Scope of the journal.
- Research question well defined, relevant & meaningful. It is stated how the research fills an identified knowledge gap.
- Rigorous investigation performed to a high technical & ethical standard.
- Methods described with sufficient detail & information to replicate.

VALIDITY OF THE FINDINGS

- **Impact and novelty is not assessed.** Meaningful replication encouraged where rationale & benefit to literature is clearly stated.
- All underlying data have been provided; they are robust, statistically sound, & controlled.
- Conclusions are well stated, linked to original research question & limited to supporting results.

Standout reviewing tips

The best reviewers use these techniques

Tip	*Example*
Support criticisms with evidence from the text or from other sources	*Smith et al (J of Methodology, 2005, V3, pp 123) have shown that the analysis you use in Lines 241-250 is not the most appropriate for this situation. Please explain why you used this method.*
Give specific suggestions on how to improve the manuscript	*Your introduction needs more detail. I suggest that you improve the description at lines 57- 86 to provide more justification for your study (specifically, you should expand upon the knowledge gap being filled).*
Comment on language and grammar issues	*The English language should be improved to ensure that an international audience can clearly understand your text. Some examples where the language could be improved include lines 23, 77, 121, 128 – the current phrasing makes comprehension difficult. I suggest you have a colleague who is proficient in English and familiar with the subject matter review your manuscript, or contact a professional editing service.*
Organize by importance of the issues, and number your points	*1. Your most important issue* *2. The next most important item* *3. …* *4. The least important points*
Please provide constructive criticism, and avoid personal opinions	*I thank you for providing the raw data, however your supplemental files need more descriptive metadata identifiers to be useful to future readers. Although your results are compelling, the data analysis should be improved in the following ways: AA, BB, CC*
Comment on strengths (as well as weaknesses) of the manuscript	*I commend the authors for their extensive data set, compiled over many years of detailed fieldwork. In addition, the manuscript is clearly written in professional, unambiguous language. If there is a weakness, it is in the statistical analysis (as I have noted above) which should be improved upon before Acceptance.*

Morpho-physiological traits and yield quality for cassava genotypes planted under drought during canopy establishment

Passamon Ittipong [1], **Poramate Banterng** [Corresp., 1, 2], **Nimitr Vorasoot** [1], **Sanun Jogloy** [1, 2], **Piyada Theerakulpisut** [3], **Kochaphan Vongcharoen** [4], **Supranee Santanoo** [3]

[1] Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand
[2] Plant Breeding Research Center for Sustainable Agriculture, Khon Kaen University, Khon Kaen, Thailand
[3] Faculty of Science, Khon Kaen University, Khon Kaen, Thailand
[4] Faculty of Science and Health Technology, Kalasin University, Kalasin, Thailand

Corresponding Author: Poramate Banterng
Email address: bporam@kku.ac.th

Growth analysis provides better insight into the adaptability of cassava genotypes grown under drought conditions during canopy establishment and full irrigation . This study aimed to determine the growth rate and starch yield of different cassava genotypes grown under irrigation and drought treatments during canopy establishment. The experiment was conducted at Khon Kaen University, Thailand from August 2021 to August 2022 (2021/2022), and it was repeated from August 2022 to August 2023 (2022/2023). A 2 x 6 split-plot design with four replications was used. The main plots were full irrigation and drought conditions during canopy establishment (90 to 150 days after planting (DAP)). Six cassava genotypes, i.e., Kasetsart 50, Rayong 9, Rayong 72, CMR38-125-77, CMR 35-91-63, and CM523-7 were assigned as subplots. Measurements of soil properties before planting, soil moisture during the growing season, crop data, and weather data were carried out. The results showed that the dry period based on drought treatment from 90 to 150 DAP reduced soil moisture and relative water contents (RWC). Rewatering after a drought supported cassava's growth rate, resulting in higher yield and biomass than irrigation treatments. The desirable genotypes for storage root dry weight, harvest index (HI), and starch yield were Rayong 72 and CMR38-125-77. The best performance in the final yield was CMR38-125-77 grown under drought treatment, and this was associated with a high crop growth rate (CGR) and relative growth rate (RGR) during the late growth phase. The findings from this study enhance decision-making in genotype classification under drought during canopy establishment.

Running title: Performance of cassava under drought during canopy establishment

Morpho-physiological traits and yield quality for cassava genotypes planted under drought during canopy establishment

Passamon Ittipong[a], Poramate Banterng[a,b*], Nimitr Vorasoot[a], Sanun Jogloy [a,b], Piyada Theerakulpisut[c], Kochaphan Vongcharoen[d] and Supranee Santanoo [c]

[a]Faculty of Agriculture, Khon Kaen University, Khon Kaen, 40002, Thailand

[b]Plant Breeding Research Center for Sustainable Agriculture, Faculty of Agriculture, Khon Kaen University, Khon Kaen, 40002, Thailand

[c]Faculty of Science, Khon Kaen University, Khon Kaen, 40002, Thailand

[d]Faculty of Science and Health Technology, Kalasin University, Kalasin, 46230, Thailand

*Corresponding author :bporam@kku.ac.th

ABSTRACT

Growth analysis provides better insight into the adaptability of cassava genotypes grown under drought conditions during canopy establishment and full irrigation. This study aimed to determine the growth rate and starch yield of different cassava genotypes grown under irrigation and drought treatments during canopy establishment. The experiment was conducted at Khon Kaen University, Thailand from August 2021 to August 2022 (2021/2022), and it was repeated from August 2022 to August 2023 (2022/2023). A 2 x 6 split-plot design with four replications was used. The main plots were full irrigation and drought conditions during canopy establishment (90 to 150 days after planting (DAP)). Six cassava genotypes, i.e., Kasetsart 50, Rayong 9, Rayong 72, CMR38-125-77, CMR 35-91-63, and CM523-7 were assigned as subplots. Measurements of soil properties before planting, soil moisture during the growing season, crop data, and weather data were carried out. The results showed that ~~the dry period based on~~ drought treatment from 90 to 150 DAP reduced soil moisture and relative water contents (RWC). Rewatering after a drought supported cassava's growth rate, resulting in higher yield and biomass than irrigation treatments. The desirable genotypes for storage root dry weight, harvest index (HI), and starch yield were Rayong 72 and CMR38-125-77. The best performance in the final yield was CMR38-125-77 grown under drought treatment, and this was associated with a high crop growth rate (CGR) and relative growth rate (RGR) during the late growth phase. The findings from this study enhance decision-making in genotype classification under drought during canopy establishment.

Keywords: drought, growth rate, irrigation, starch yield

1. Introduction

Cassava (*Manihot esculenta* Crantz) is extensively cultivated in Africa, Asia, and Latin America, and it plays a vital role in food, animal feed, and bioethanol (Bayata, 2019; Ferguson et al., 2019). Thailand is a major cassava producer that produced 35.10 million tons, the harvested area was 1.67 million hectares, and the average yield was 21.44 tons per hectare (Office of Agricultural Economics, 2023). However, the average yield for Thailand is lower than expected (National Science and Technology Development Agency, 2012). The major cassava growing area in Thailand is in the Northeast, which has sandy soils with poor soil fertility, low soil water holding capacity, and unpredicted rainfall. Cassava production in this region has been planted in two seasons, i.e., the rainy and the late rainy seasons (Polthanee, 2018). For growing cassava in the late rainy season, storage root yield can be affected by drought during the early growth phase (the canopy establishment), and it causes decreasing yield by approximately 32 to 60 percent (Palanivel & Shah, 2021). There are several options for increasing cassava yields for drought-prone areas, e.g., application of supplemental irrigation and selection of suitable cassava genotypes. Recommendation of the cassava genotypes that can adapt well under drought conditions is a strategy to help the farmer in achieving high productivity with low investment.

Determinations of cassava genotypes based on agronomic traits, physiological traits, and starch content have been done for different water regimes. Photosynthesis, growth, productivity, and nutrient use efficiency among cassava genotypes under rainfed conditions were documented by El-Sharkawy & de Tafur (2010). In arid and semi-arid lands, different cassava genotypes were evaluated under drought and irrigated conditions in agro-climatic zone five (ACZ-V) (Orek et al., 2020). Wongnoi et al. (2020) studied the performance of different cassava genotypes in upland in a dry environment during the high storage root accumulation stage. Various cassava genotypes grown under different irrigation levels (100%, 60%, and 20% crop water requirement (ET crop)) during the early growth phase were reported (Ruangyos et al., 2024). Mahakosee et al. (2019) reported a Rayong 9 cassava genotype grown under rainfed and irrigated conditions. Growth and yield of cassava genotypes grown under rainfed upper paddy field conditions were assessed (Sawatraksa et al., 2018 and 2019). These studies did not cover comparing the performances of some cassava genotypes for drought conditions during the canopy establishment and under full irrigation.

Photosynthesis, carbohydrate partitioning, growth, and yield for different cassava genotypes under full irrigation and early drought (Santanoo et al., 2024). However, this report was only based on a single experiment, and an additional experiment is necessary for better explanations. In addition, morpho-physiological traits and yield quality based on growth analysis for cassava offer valuable insights into crop growth habits, aiding in the selection of suitable cassava varieties for various environments (Phuntupan & Banterng, 2017; Phoncharoen et al., 2019; Sawatraksa et al., 2019; Ruangyos et al., 2024). The information on growth analysis can help design suitable cassava genotypes for the dry period during the early growth phase and provide appropriate water management practices. Growth analysis for cassava on the basis of crop growth rate (CGR), stem growth rate (SGR), leaf growth rate (LGR), storage root growth rate (SRGR) and relative growth rate (RGR) for different cassava genotypes can support a better understanding of cassava adaptability in different growing environments. Previous studies mentioned growth analysis for cassava growing under different nitrogen fertilizer applications (Phuntupan & Banterng, 2017), various environments (Sawatraksa et al., 2018), and different planting dates (Phoncharoen et al., 2019a). However, an investigation on the performance of varying cassava genotypes in terms of growth rate under non-irrigation (drought conditions) during the canopy establishment and under full irrigation is still necessary for a tropical savanna climate (Aw). This study aimed to determine the growth rate and starch yield of different cassava genotypes grown under irrigation and drought during canopy establishment.

2. Materials and methods

2.1. Experimental detail

This experiment was conducted under field conditions from August 2021 to August 2022 (2021/2022) and from August 2022 to August 2023 (2022/2023) at the Field Crop Research Station of Khon Kaen University, Khon Kaen, Thailand (16˚28´ N, 102˚48´ E, 200 m asl). The soil type for the experimental field was Yasothon Series (Yt: Oxic Paleustults). The experiment was a 2 x 6 split plot design with four replications. Two water regimes including drought conditions in the dry season and full irrigation were assigned as main plots. Six cassava genotypes, Kasetsart 50, Rayong 9, Rayong 72, CMR38-125-77, CMR 35-91-63, and CM523-7, were assigned as subplots. The cassava genotypes were identified as highly adapted to the environment (Kasetsart 50), high yield and high starch content (Rayong 9 and CMR38-125-77), high yield and drought tolerance (Rayong 72), high yield (CMR35-91-63) and low yield and drought tolerance (CM523-7).

Land preparation and tillage were conducted, and soil ridges were created with a distance between the ridge of 1 m. The plot size was 7 x 10 m. Cassava stem cuttings of 20 cm from healthy 12-month-old plants were planted at 1 x 1 m after soaking for 15 minutes in thiamethoxam [3-(2-chloro-thiazol-5-ylmethyl)-5-methyl-(1,3,5)-oxadia-zinan-4-ylidene-N-nitroamine, 25% water-dispersible granules] to prevent pest infestation. The stakes were inserted vertically to a depth of 14 cm or 2/3 length of the stick into the soil ridges. Manual weed control was conducted between 30 to 90 days after planting (DAP). Chemical fertilizer of 15-7-18 (N-P_2O_5-K_2O) was applied at a rate of 312.5 kg ha^{-1}. From 30 to 90 days after planting (DAP), full irrigation was applied to all experimental plots. In the dry season (90 to 150 DAP), drought treatment was imposed, and supplementary irrigation was applied back for the recovery period during 151 to 360 DAP. For the plots that received full irrigation, the plants were irrigated throughout the crop duration. Irrigation was conducted based on the amount of crop water requirement (ETcrop) that was calculated as described by Doorenbos & Pruitt (1992):

$$ET\ crop = ETo \times Kc \qquad (1)$$

where ET crop is the crop requirement (mm day^{-1}), Eto is the evapotranspiration of a reference plant under specified conditions calculated by the pan evaporation method and Kc is the crop water requirement coefficient that varies as a function of the growth stage. The amount of water for irrigation was then calculated.

2.2. Data collection

Before planting, soil at 0-30 cm and 30-60 cm depths were sampled to assess physical and chemical properties (Table 1). The soil texture at the Field Crop Research Station of Khon Kaen University was a sandy loam, the values for soil pH ranged from 6.3 to 6.8, total nitrogen varied from 0.2 to 0.3 g kg^{-1}, available phosphorus was between 8.0 to 36.8 mg kg^{-1}, and exchangeable potassium varied from 13.6 to 54.7 mg kg^{-1}. The soil chemical analysis indicated a low total nitrogen and exchangeable potassium.

Measurements of soil moisture were taken at 90, 120, 150, 180, and 360 DAP at depths of 0-30 cm and 30-60 cm. The soil samples were oven-dried at 105˚C for 72 h or until weights were constant and the moisture percentage was calculated. Soil moisture was determined by the gravimetric method described by Shukla et al. (2014) as below (2):

$$\text{Soil moisture content (\%)} = \frac{\text{Soil wet weight (g)} - \text{Soil dry weight (g)}}{\text{Soil dry weight (g)}} \text{ x } 100 \qquad (2)$$

Crop data were collected from two plants of each plot at 90, 120, 150, 180, and 360 DAP. The plants were separated into leaves, stems, storage roots, and fibrous roots. All plant parts were subsampled) about 10% of the total fresh weight of each organ). A subsample of fresh leaves was then used to measure leaf area by using a leaf area meter (LI-3100, LI-Cor). Subsamples were oven-dried at 80 °C to achieve a constant dry weight. Calculations for crop growth rate (CGR), leaf growth rate (LGR), and stem growth rate (SGR) during 90 to 120 DAP, 120 to 150 DAP, 150 to 180 DAP, and 180 to 360 DAP were performed based on the function below (Sawatraksa et al., 2019) (3):

$$CGR\ (g\ m^{-2} d^{-1}) = (\frac{1}{G}) x (\frac{DW_2 - DW_1}{T_2 - T_1}) \quad (3)$$

where G is sample area (m^2) and DW_1 and DW_2 are crop dry weight (g) at the times T_1 and T_2 (d). The equation for CGR was applied to calculate LGR and SGR.

Relative growth rate (RGR) was calculated using the following equation (Sawatraksa et al., 2019) (4):

$$RGR\ (g\ g^{-1}\ d^{-1}) = \frac{\ln(DW_2) - \ln(DW_1)}{T_2 - T_1} \quad (4)$$

where DW_1 and DW_2 are crop dry weight (g) at the times T_1 and T_2 (d).

2.3. Statistical Analysis

Analysis of variance (ANOVA) was performed for all crop traits by following a model for split-plot design (Gomez & Gomez, 1984) and by using the statistix10 program (Statistix10, 2013). Mean comparisons were conducted for the least significant difference test (LSD).

3. Results

The weather data shows that the drought treatment we applied from November to January coincided with the low rainfall period for both the 2021/2022 and 2022/2023 growing seasons (Figure 1), which is generally observed for most of the years in Thailand. This period was recognized for its cooler and drier conditions, characterized by lower temperatures and reduced rainfall compared to other times.

The information on soil moisture content during growing seasons was shown in Figure 2, indicating that the values of soil moisture content for full irrigation treatment for the 2021/2022 growing season were close to field capacity (FC) values for both soil depths (Figure 2a). On the other hand, the values of soil moisture content for drought treatment during 120 to 150 DAP (during canopy establishment) for both soil depths were lower than FC values (Figure 2b), and the value of soil moisture content at a depth of 30 cm for 150 DAP was close to the permanent wilting point (PWP). Similar results were found for the 2022/2023 growing season (Figure 2c, d).

The RWC value indicates the water content in a leaf at sampling compared to its maximum capacity. The results revealed an interaction between water treatment and genotype (data not shown), indicating the different responses of six cassava genotypes in two water regimes. In comparison between water treatments, the drought treatment exhibited lower RWC values than the irrigated treatment during the 2021/2022 and 2022/2023 growing seasons (Figure 3).

Based on the effect of the drought treatment during 90 to 150 DAP, Kasetsart 50, CMR38-125-77, and CM523-7 for 2021/2022 growing season and Rayong 9, Rayong 72, CMR38-125-77, and CM523-7 for 2022/2023 growing season, showed the highest RWC values at 120 DAP (Figure 4). For 150 DAP, it marks the peak of a dry period, as evidenced by the very low soil moisture content (Figure 2). The highest RWC values were observed from CMR35-91-63 for 2021/2022 growing season and Kasetsart 50 and CMR35-91-63 for 2022/2023 growing season.

In terms of growth rate for the 2021/2022 growing season, the results indicated the different responses of six cassava genotypes in two water regimes (Table 2). The drought treatment during 90 to 150 DAP provided higher LGR and SGR than the irrigation treatment, but not SRGR. Comparing growth rates from 90 to 150 DAP among different cassava genotypes, Rayong 72 had a value of LGR, while CMR38-125-77 exhibited SGR and SRGR that were higher than those of the other genotypes. After the drought during the early growth phase, full irrigation was applied to all experimental plots, resulting in higher LGR and SRGR (from 180 to 360 DAP) for the drought treatment compared to the irrigation treatment. Among different cassava genotypes, the highest growth rate values from 150 to 180 DAP were observed for CMR35-91-63 in terms of LGR and SGR, and for Rayong 72 based on SRGR. Kasetsart 50 displayed higher LGR, SGR, and SRGR values from 180 to 360 DAP compared to the other genotypes.

For CGR and RGR for the 2021/2022 growing season, different effects of two water regimes on six cassava genotypes were found, as indicated by an interaction between water treatment and genotype, except for RGR for 90 to 150 DAP (Table 3). CGR and RGR during the periods of 90 to 150 were not different between the two water regimes, but it was not the same for CGR during 150 to 180 and 180 to 360 DAP and RGR from 150 to 360. CMR38-125-77 exhibited the highest CGR values for all ranges: 90 to 150, 150 to 180, and 180 to 360 DAP, compared to the other tested genotypes. Rayong 9 and CMR35-91-63 had a greater value of RGR for 150 to 360 than the other genotypes.

According to the final harvest data for the 2021/2022 growing season (Table 4), the interaction between water regime and genotype for storage root fresh weight, storage root dry weight, total dry weight, harvest index (HI), and starch yield indicated the various responses of six cassava genotypes in two water regimes. The drought treatment produced more storage root dry weight, total dry weight, HI, and starch contents than the irrigation treatment. Comparing among genotypes, Rayong 72 performed well for almost all traits, except for total dry weight. CMR38-125-77 showed well in storage root dry weight, HI, and starch yield.

Based on the growth rate for the 2022/2023 growing season, the results showed an interaction between water regimes and cassava genotype (Table 5). During 90 to 150 DAP, the drought treatment gave higher LGR and SRGR values than the irrigation treatment. Among the tested genotypes, the highest growth rate values were observed for CMR38-125-77 regarding LGR, Rayong 72 and CM523-7 for SGR, and Rayong 72 for SRGR. During the late growth phase, all experimental plots received full irrigation. This led to drought treatment having a higher LGR during 180 to 360 DAP and SRGR from 150 to 360 DAP compared to irrigation treatment. Comparing among genotypes, the highest LGR values were recorded for CMR35-91-63 during 150 to 180 DAP and Rayong 72 from 180 to 360 DAP. For SGR, Kasetsart 50, CMR38-125-77, and CMR35-91-63 had the highest values for 150 to 180 DAP and CMR35-91-63 for 180 to 360 DAP. The highest SRGR for the ranges of 150 to 180 and 180 to 360 DAP was identified from CMR35-91-63.

Regarding CGR and RGR for the 2022/2023 growing season, the interaction between water regime and genotype indicated the response variation of six cassava genotypes to different water regimes (Table 6). Among water regimes, irrigation treatment gave higher CGR from 90 to 150 and 150 to 180 DAP, but not for 180 to 360 DAP. A greater value of RGR from 150 to 360 DAP was recorded for the drought treatment. In comparison between cassava genotypes, CMR35-91-63 showed the highest CGR from 90 to 150 and from 150 to 180 DAP, and Rayong 9 recorded the highest CGR from 180 to 360 DAP. Rayong 72 and CM523-7 demonstrated the highest RGR for 150 to 360.

In the final harvest data for the 2022/2023 growing season (Table 7), the responses of six cassava genotypes under two water regimes were different for all crop traits. The drought treatment produced higher storage root dry weight, total crop dry weight, HI, and starch yield than the irrigation treatment. CMR38-125-77 is a desirable genotype for almost all crop traits, except for storage root fresh weight.

4. Discussion

This study focused on the growth analysis of different cassava genotypes under drought during the canopy establishment and full irrigation. The findings can help select suitable cassava genotypes for dry periods during early growth and develop effective water management practices. The soil moisture content and RWC were used to explain water status in soil and crops during the growing season. Low rainfall from 90 to 150 DAP (Figure 1) decreased soil moisture contents (Figure 2) and led to a low value of RWC (Figure 3) for both the 2021/2022 and 2022/2023 growing seasons. The RWC value was used to indirectly measure soil water status during cassava cultivation across different water regimes in Thailand (Ruangyos et al., 2024; Sawatraksa et al., 2018; Wongnoi et al., 2020).

The genotype with high RWC value during the dry periods serves as a mechanism for drought resistance, resulting from either enhanced osmotic regulation or reduced elasticity of tissue cell walls (Ritchie et al., 1990). As indicated by high RWC values (Figure 4) during the peak of the dry period (150 DAP) for both the 2021/2022 and 2022/2023 growing seasons (Figure 2). Therefore, CMR35-91-63 would be classified as a genotype with a good balance of the water content between leaves and water shortage conditions during the early growth phase.

This study shows that even though cassava faces drought conditions during its early growth phase, it can still produce desirable results if there is supplementary irrigation or rainfall in the later growth phase. The dry period from 90 to 150 DAP in this study, therefore, did not decrease the final yield but produced more biomass and yield than the irrigation treatments (Tables 4 and 7). Cassava is a remarkably drought-resistant crop that can thrive with minimal water during its growth period (El-Sharkawy, 1993; El-Sharkawy et al., 2012; Howeler, 2002;

Howeler et al., 2013; Sawatraksa et al., 2018). Santanoo et al. (2024) conducted a single-year experiment on the photosynthetic performance and growth of different cassava genotypes grown under the dry period during the early growth phase and irrigation treatment. They found that net photosynthesis rate (Pn), petiole, root dry weight, leaf, stem, and storage root dry weight were reduced after 60 days of the dry period. After 30 days of rewatering, Pn fully recovered, leading to a significantly higher dry weight at 12 months after planting for the drought treatment than the irrigation treatment. Mahakosee et al. (2019) planted cassava genotype cv. Rayong 9 under drought and irrigated conditions in Thailand. They found that the drought treatment with a planting date during the early growth phase, which had a dry period, produced higher storage root fresh weight, storage root dry weight, and total crop dry weight than the irrigation treatment.

The study on growth rate during different growing periods, along with crop dry weights at the final harvest, offers valuable insights into growth habits and enhances our understanding of adaptability. The drought treatment exhibited greater values of LGR than irrigation treatment during 90 to 150 DAP for both 2021/2022 and 2022/2023 growing seasons (Tables 2 and 5). This pointed out that not watering cassava during the dry season, when it was 90 to 150 DAP, had a positive effect on leaf growth. For the growth rate of other crop organs during 90 to 150 DAP, however, the drought treatment led to smaller SRGR and SGR for the 2021/2022 and 2022/2023 growing seasons, respectively, as compared to irrigation treatment. The 2021/2022 and 2022/2023 growing seasons demonstrated that the dry period from 90 to 150 DAP resulted in lower CGR for the drought treatment than the irrigation treatment (Tables 3 and 6). However, cassava grown under the drought treatment during 90 to 150 DAP and receiving full irrigation during 151 to 360 DAP gave higher CGR from 180 to 360 DAP and RGR from 150 to 360 DAP, leading to more storage root dry weight, total dry weight, HI, and starch yield than the full irrigation treatment for the whole crop duration (Tables 4 and 7). CGR in the late growth period was identified as a physiological determinant of storage root dry weight for cassava grown under different nitrogen applications (Phuntupan & Banterng, 2017). Phoncharoen et al. (2019a) reported that SRGR during 300-360 DAP and LGR during 60-120 and 300-360 DAP were the components for the physiological determinants of total crop and storage root dry weights for cassava genotypes grown under different planting dates.

Based on the performance among cassava genotypes, the 2021/2022 growing season highlighted that Rayong 72 and CMR38-125-77 excelled in storage root dry weight, HI, and starch yield (Table 4). Also, CMR38-125-77 was identified as the superior genotype for these crop traits for the 2022/2023 growing season (Table 7). The good performance of these two cassava genotypes regarding storage root dry weight, HI, and starch yield is associated with the varying growth rates of plant organs at different times. For example, in the 2021/2022 growing season (Table 2), Rayong 72 exhibited high LGR from 90 to 150 DAP and SRGR from 150 to 180 DAP. Meanwhile, CMR38-125-77 demonstrated high SGR and SRGR during the 90 to 150 DAP range. To determine the relationship between these final harvest data and CGR, however, high values of CGR for CMR38-125-77 during the 2021/2022 growing season are associated with high storage root dry weight, HI, and starch yield (Tables 3, 4, 6, and 7).

A comparison of six genotypes grown under two different water regimes showed that CMR38-125-77 under drought treatments exhibited good in storage root fresh weight, storage root dry weight, total dry weight, and starch yield for both the 2021/2022 and 2022/2023 growing seasons as compared to the other genotypes (Tables 4 and 7). These final harvest data of CMR38-125-77 under drought treatment related to high CGR during 180 to 360 DAP in the 2021/2022 growing season (Table 3) and a large value of RGR from 150 to 360 DAP in the

2022/2023 growing season (Table 6). This suggests that the high productivity of cassava can be attributed to either the rapid accumulation of biomass over a specified period (CGR) (Phuntupan & Banterng, 2017) or the plant's strong ability to recover after experiencing drought stress (RGR) (Awal & Ikeda, 2002; Abid et al., 2016; Ruangyos et al., 2024; Vandegeer et al., 2013).

A study about growth analysis of different cassava genotypes grown under different planting dates by Phoncharoen et al. (2019a, 2019b) reported that CMR 38-125-77 is likely to be a good genotype concerning total crop dry weight and storage root dry weight at final harvest for almost all growing dates. The previous study has also recorded the desirable performance in chlorophyll fluorescence of a CMR 38-125-77 genotype grown after rice harvesting and under rain-fed upper paddy field conditions (Sawatraksa et al., 2018). Wongnoi et al. (2020) have mentioned the desirable physiology, growth, and yield characteristics of a genotype CMR 38-125-77 grown in upland fields under a dry environment during the maximum storage root accumulation phase. A study by Ruangyos et al. (2023) regarding the evaluation of the physiological performance of different cassava genotypes grown under different irrigation levels also found that a CMR 38-125-77 had a high net photosynthesis rate compared to other genotypes.

Selection of the superior cassava genotypes under different growing conditions based on only final yield is inefficient and analysis of morpho-physiological traits can provide useful information (Phoncharoen et al., 2019a; Phuntupan & Banterng, 2017; Sawatraksa et al., 2018). This study offers a better understanding of how particular cassava genotypes perform under drought during canopy establishment, and it could support decision-making in identifying suitable genotypes within a given environment.

5. Conclusions

The drought treatment during the canopy establishment (from 90 to 150 DAP) decreased soil moisture contents and RWC. Rewatering after the drought period could enhance the growth rate of cassava and produce a higher final yield and biomass than irrigation treatments. The preferred genotypes for storage root dry weight, HI, and starch yield were Rayong 72 and CMR38-125-77 for the 2021/2022 growing season, and CMR38-125-77 for the 2022/2023 growing season. In addition, the best performance in the final yield was CMR38-125-77 grown under drought treatment, and this was related to high CGR during 180 to 360 DAP in the 2021/2022 growing season and high RGR from 150 to 360 DAP in the 2022/2023 growing season.

Acknowledgments

This study was supported by Khon Kaen University, Thailand, the Royal Golden Jubilee Ph.D. Program (N41A661180). Assistance in conducting the work was also received from the Plant Breeding Research Center for Sustainable Agriculture, Khon Kaen University and from the National Science and Technology Development Agency (NSTDA). We utilized Grammarly, a free artificial intelligence (AI) writing assistant, to refine the language and improve the quality of our manuscript.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ORCID

Passamon Ittipong. https://orcid.org/ 0009-0005-9988-6087

Poramate Banterng. https://orcid.org/0000-0003-3535-8718

Sanun Jogloy. https://orcid.org/0000-0001-7455-4514

Nimitr Vorasoot. https://orcid.org/0000-0003-4164-8148

Piyada Theerakulpisut. https://orcid.org/0000-0001-5495-2953

Kochaphan Vongcharoen. https://orcid.org/0000-002-0057-5045

Supranee Santanoo. https://orcid.org/ 0009-0003-0267-1510

References

Awal, M. A., & Ikeda, T. (2002). Recovery strategy following the imposition of episodic soil moisture deficit in stands of peanut (*Arachis hypogaea* L.). *Journal of Agronomy and Crop Science*, 188, 185–192. https://doi.org/10.1046/j.1439-037X.2002.00558.x

Abid, M., Tian, Z., Ata-Ul-Karim, S. T., Wang, F., Liu, Y., Zahoor, R., Jiang, D., & Dai, T. (2016). Adaptation to and recovery from drought stress at vegetative stages in wheat (Triticum aestivum) cultivars. *Functional Plant Biology*, 43, 1159–1169. https://doi.org/10.1071/FP16150

Bayata, A. (2019). Review on nutritional value of cassava for use as a staple food. Science *Journal of Analytical Chemistry*, 7, 83–91. https://doi.org/10.11648/j.sjac.20190704.12

El-Sharkawy, M. A. (1993). Drought–tolerant cassava for Africa, Asia and Latin America: Breeding projects work to stabilize productivity without increasing pressures on limited natural resources. *BioScience*, 43, 441–451. https://doi.org/10.2307/1311903

El-Sharkawy, M. A., & de Tafur, S. M. (2010). Comparative photosynthesis, growth, productivity, and nutrient use efficiency among tall– and short–stemmed rain–fed cassava cultivars. *Photosynthetica*, 48, 173–188. https://doi.org/10.1007/s11099-010-0023-6

El-Sharkawy, M. A., de Tafur, S. M., & Lopez, Y. (2012). Eco-physiological research for breeding improved cassava cultivars in favorable and stressful environments in tropical/subtropical bio-systems. *Environmental Research Journal*, 6, 143–212. https://doi.org/10.13140/2.1.1823.0409

Ferguson, M. E., Shah, T., Kulakow, P., & Ceballos, H. (2019). A global overview of cassava genetic diversity. *PLOS ONE*, 14, 1–16. https://doi.org/10.1371/journal.pone.0224763

Gomez, K. A., & Gomez, A. A. (1984). Statistical Procedures for Agricultural Research. John Wiley and Sons, New York.

Howeler, R. H. (2002). Cassava mineral nutrition and fertilization. In: R. J. Hillocks et al. (Eds), *Cassava: Biology, Production and Utilization* (pp. 115–136). CABI Publishing, Wallingford, Oxon, United Kingdom.

Howeler, R. H., Lutaladio, N., & Thomas, G. (2013). Cassava, a 21st century crop. In: Save and Grow, *Cassava, A Guide to Sustainable Production Intensification* (pp. 1–18). Food and Agriculture Organization of the United Nations, Rome, Italy.

Mahakosee, S., Jogloy, S., Vorasoot, N., Theerakulpisut, P., Banterng, P., Kesmala, T., Holbrool, C., & Kvien, C. (2019). Seasonal variations in canopy size and yield of Rayong 9 cassava genotype under rainfed and irrigated conditions. *Agronomy*, 9, 1–20. https://doi.org/10.3390/agronomy9070362

National Science and Technology Development Agency. (2012). *Strategic Planning Alliance II: SPA II*. National Science and Technology Development Agency, Bangkok, Thailand.

Office of Agricultural Economics. (2023). *Agricultural statistics of Thailand 2022*. Office of Agricultural Economics, Bangkok, Thailand.

Orek, C., Gruissem, W., Ferguson, M., & Vanderschuren, H. (2020). Morpho-physiological and molecular evaluation of drought tolerance in cassava (*Manihot esculenta* Crantz). *Field Crops Research*, 255, 107861. https://doi.org/10.1016/j.fcr.2020.107861

Palanivel, H., & Shah, S. (2021). Unlocking the inherent potential of plant genetic resources: food security and climate adaptation strategy in Fiji and the Pacific. *Environment, Development and Sustainability*, 23, 14264–14323. https://doi.org/10.1007/s10668-021-01273-8

Phoncharoen, P., Banterng, P., Vorasoot, N., Jogloy, S., Theerakulpisut, P., & Hoogenboom, G. (2019a). Growth rates and yields of cassava at different planting dates in a tropical savanna climate. *Scientia Agricola*, 76, 376–388. https://doi.org/10.1590/1678-992X-2017-0413

Phoncharoen, P., Banterng, P., Vorasoot, N., Jogloy, S., Theerakulpisut, P., & Hoogenboom, G. (2019b). The impact of seasonal environments in a tropical savanna climate on forking, leaf area index, and biomass of cassava genotypes. *Agronomy*, 9, 19. https://doi.org/10.3390/agronomy9010019

Phuntupan, K., & Banterng, P. (2017). Physiological determinants of storage root yield in three cassava genotypes under different nitrogen supply. *The Journal of Agricultural Science*, 155, 978–992. https://doi.org/10.1017/S0021859617000053

Polthanee, A. (2018). Cassava as an insurance crop in a changing climate: The changing role and potential applications of cassava for smallholder farmers in Northeastern Thailand. *Forest and Society*, 2, 121–137. https://doi.org/10.24259/fs.v2i2.4275

Ritchie, S. W., Nguyen, H. T., & Holaday, A. S. (1990). Leaf water content and gas exchange parameters of two wheat genotypes differing in drought resistance. *Crop Science*, 30, 105–111. https://doi.org/10.2135/cropsci1990.0011183X003000010025x

Ruangyos, C., Banterng, P., Vorasoot, N., Jogloy, S., Theerakulpisut, P., Vongcharoen, K., & Hoogenboom, G. (2024). Variation in biomass of cassava genotypes grown under different irrigation levels during the early growth phase. *Crop Science*, 64, 482–495. https://doi.org/10.1002/csc2.21127

Santanoo, S., Ittipong, P., Banterng, P., Vorasoot, N., Jogloy, N., Vongcharoen, K., & Theerakulpisut, P. (2024). Photosynthetic performance, carbohydrate partitioning, growth, and yield among cassava genotypes under full Irrigation and early drought treatment in a tropical savanna climate. *Plants*, 13, 2049. https://doi.org/10.3390/plants13152049

Sawatraksa, N., Banterng, P., Jogloy, S., Vorasoot, N., & Hoogenboom, G. (2018). Chlorophyll fluorescence and biomass of four cassava genotypes grown under rain-fed upper paddy field conditions in the tropics. *Journal of Agronomy and Crop Science*, 204, 554–565. https://doi.org/10.1111/jac.12285

Sawatraksa, N., Banterng, P., Jogloy, S., Vorasoot, N., & Hoogenboom, G. (2019). Cassava growth analysis of production during the off-season of paddy rice. *Crop Science*, 59, 1–12. https://doi.org/10.2135/cropsci2018.07.0435

Statistix10. (2013). Statistix10: Analytical software user's manual. Tallahassee, Florida. Available online: https://www.statistix.com/.

Vandegeer, R., Rebecca, E., Bain, M., Roslyn, M., & Timothy, R. (2013). Drought adversely affects tuber development and nutritional quality of the staple crop cassava (*Manihot esculenta* Crantz). *Functional Plant Biology*, 40, 195–200. https://doi.org/10.1071/FP12179

Wongnoi, S., Banterng, P., Vorasoot, N., Jogloy, S., & Theerakulpisut, P. (2020). Physiology, growth and yield of different cassava genotypes planted in upland with dry environment during high storage root accumulation stage. *Agronomy*, 10, 576–593. https://doi.org/10.3390/agronomy10040576

Table 1(on next page)

Physical and chemical properties of the soil for depths of 0-30 and 30-60 cm.

Each data point indicates the average value for for depths of 0-30 and 30-60 cm.

Table 1:

Physical and chemical properties of the soil for depths of 0-30 and 30-60 cm.

Soil property	**2021/2022**		**2022/2023**	
	0–30 cm	**30–60 cm**	**0–30 cm**	**30–60 cm**
Physical property				
Texture class	Sandy loam	Sandy loam	Sandy loam	Loamy sand
Sand (%)	75.0	71.0	82.9	67.9
Silt (%)	18.0	17.0	11.8	18.1
Clay (%)	7.0	12.1	5.4	14.1
Chemical property				
pH (1:1 H_2O)	6.4	6.3	6.4	6.8
Cation exchange capacity (cmol kg^{-1})	3.3	3.6	2.9	4.3
Electrical conductivity (dS m^{-1})	0.03	0.02	0.02	0.02
Organic matter (g kg^{-1})	4.3	2.9	2.9	1.9
Total nitrogen (g kg^{-1})	0.3	0.2	0.2	0.2
Available phosphorus (mg kg^{-1})	36.8	27.8	27.5	8.0
Exchangeable potassium (mg kg^{-1})	54.7	21.3	13.6	18.2

Table 2 (on next page)

Means for leaf growth rate (LGR), stem growth rate (SGR), and storage root growth rate (SRGR) during 90–150, 150–180, and 180–360 days after planting (DAP) of six cassava genotypes under two water regimes in the 2021/2022 growing season.

Each data point indicates the average performance of six cassava genotypes under two water regimes in the 2021/2022 growing season.

Table 2:

Means for leaf growth rate (LGR), stem growth rate (SGR), and storage root growth rate (SRGR) during 90–150, 150–180, and 180–360 days after planting (DAP) of six cassava genotypes under two water regimes in the 2021/2022 growing season.

Treatment	LGR (g day^{-1})			SGR (g day^{-1})			SRGR (g day^{-1})		
	90–150 DAP	150–180 DAP	180–360 DAP	90–150 DAP	150–180 DAP	180–360 DAP	90–150 DAP	150–180 DAP	180–360 DAP
Water treatment (W)									
Drought (W1)	0.18A	0.59B	2.90A	3.0A	6.0B	2.0	8.6B	11.7	11.1A
Irrigation (W2)	0.13B	0.91A	1.11B	2.2B	8.4A	2.0	11.6A	12.0	4.9B
F-test	*	*	**	**	**	NS	**	NS	**
C.V. (%)	29.53	16.74	28.14	15.29	2.94	20.85	7.92	8.97	21.45
Genotype (G)									
Kasetsart 50 (G1)	0.07E	0.72B	3.06A	2.5B	8.0B	3.2A	7.1E	12.5B	10.7A
Rayong 9 (G2)	0.08E	0.63B	2.30B	2.5B	6.0D	1.3C	8.8D	11.6B	10.0A
Rayong 72 (G3)	0.26A	0.54B	1.59C	2.0C	5.0E	1.3C	10.0C	15.5A	5.8C
CMR38-125-77 (G4)	0.17C	0.69B	2.10B	3.2A	6.7C	1.6C	15.4A	9.8C	4.7C
CMR35-91-63 (G5)	0.21B	1.29A	1.50C	2.6B	12.2A	2.1B	6.5E	9.8C	7.3B
CM523-7 (G6)	0.14D	0.65B	1.51C	2.7B	5.6D	2.5B	12.8B	12.0B	9.56
F-test	**	**	**	**	**	**	**	**	**
G x W									
W1 x G1	0.04E	0.55B-E	4.70A	3.5B	6.8D	3.7A	5.8E	7.0GH	14.5A
W1 x G2	0.13D	0.64B-E	3.03C	3.1BC	7.1CD	0.3E	7.2DE	8.2FG	12.2B
W1 x G3	0.32A	0.30E	2.34D	1.1FG	4.9E	1.1CD	12.2B	19.9A	9.3C
W1 x G4	0.15CD	0.87BC	4.05B	3.4B	4.9E	0.8DE	13.1B	13.6BC	4.8EF
W1 x G5	0.30A	0.80BC	1.75E	4.3A	7.7C	3.6A	5.8E	12.4CD	13.1AB
W1 x G6	0.16B-D	0.38DE	1.50EF	2.8CD	4.8E	2.8B	7.3D	9.3EF	12.5AB
W2 x G1	0.11D	0.89B	1.41EF	1.6EF	9.1B	2.8B	8.4D	18.0A	7.0C-E
W2 x G2	0.04E	0.63B-E	1.57E	1.9E	4.9E	2.3B	10.4C	15.0B	7.8CD
W2 x G3	0.20B	0.78B-D	0.84F	2.9B-D	5.1E	1.6C	7.7D	11.0DE	2.2G
W2 x G4	0.20BC	0.51C-E	0.15G	3.1BC	8.4B	2.5B	17.7A	5.9H	4.5F
W2 x G5	0.12D	1.77A	1.19EF	1.0G	16.8A	0.7DE	7.2DE	7.2GH	1.5G
W2 x G6	0.11D	0.92B	1.51E	2.5D	6.4D	2.2B	18.2A	14.7B	6.6D-F
F-test	**	**	**	**	**	**	**	**	**
C.V. (%)	14.74	11.87	19.87	13.13	7.51	21.69	9.95	10.43	18.50

Note: Different letters in the same column represent significant differences (least significant difference test). NS, *, ** = non-significant, significant at $p \leq 0.05$ and significant at $p \leq 0.01$ level, respectively.

Table 3 (on next page)

Means for crop growth rate (CGR) and relative growth rate (RGR) of six cassava genotypes under two water treatments in the 2021/2022 growing season.

Each data point indicates the average performance of six cassava genotypes under two water treatments in the 2021/2022 growing season.

Table 3:

Means for crop growth rate (CGR) and relative growth rate (RGR) of six cassava genotypes under two water treatments in the 2021/2022 growing season.

Treatment	CGR ($g\ m^{-2}\ day^{-1}$)			RGR x 10^{-2} ($g\ day^{-1}$)	
	90–150 DAP	150–180 DAP	180–360 DAP	90–150 DAP	150–360 DAP
Water treatment (W)					
Drought (W1)	14.7	18.1B	9.1A	2.2	0.49A
Irrigation (W2)	15.3	40.6A	3.6B	2.7	0.39B
F-test	NS	**	**	NS	*
C.V. (%)	5.25	6.75	13.04	30.60	16.77
Genotype (G)					
Kasetsart 50 (G1)	11.4D	32.4AB	6.4B	2.0B	0.41B
Rayong 9 (G2)	17.8B	18.0D	8.1A	2.8A	0.62A
Rayong 72 (G3)	18.4B	28.4C	5.6BC	2.6A	0.28D
CMR38-125-77 (G4)	19.7A	32.6AB	8.5A	2.4AB	0.34C
CMR35-91-63 (G5)	13.0C	35.3A	5.1BC	2.1B	0.64A
CM523-7 (G6)	9.6E	29.5BC	4.5C	2.8A	0.34C
F-test	**	**	**	**	**
G x W					
W1 x G1	10.1E	39.2B	5.8E-G	2.0	0.45C
W1 x G2	10.6E	2.8G	11.1AB	2.6	0.94A
W1 x G3	24.4A	28.0D	8.1CD	2.6	0.26FG
W1 x G4	17.2C	5.5G	12.3A	1.6	0.43CD
W1 x G5	12.4D	14.0F	9.6BC	2.2	0.62B
W1 x G6	13.3D	19.2E	7.8C-E	2.2	0.25FG
W2 x G1	12.7D	25.6D	6.9D-F	2.1	0.36DE
W2 x G2	25.0A	33.3C	5.2F-H	3.0	0.31EF
W2 x G3	12.3D	28.7CD	3.2HI	2.6	0.31EF
W2 x G4	22.1B	59.7A	4.6GH	3.2	0.24G
W2 x G5	13.5D	56.7A	0.7J	2.1	0.67B
W2 x G6	5.8F	39.8B	1.11IJ	3.4	0.42CD
F-test	**	**	**	NS	**
C.V. (%)	6.35	11.15	11.12AB	18.35	8.82

Note: Different letters in the same column represent significant differences (least significant difference test). NS, *, ** = non-significant, significant at $p \leq 0.05$ and significant at $p \leq 0.01$ level, respectively.

Table 4(on next page)

Means for storage root fresh weight, storage root dry weight, total dry weight, harvest index (HI), and starch yield at 360 days after planting (DAP) of six cassava genotypes under two water treatments in 2021/2022 growing season .

Each data point indicates the average performance of six cassava genotypes under two water treatments in 2021/2022 growing season .

Table 4:

Means for storage root fresh weight, storage root dry weight, total dry weight, harvest index (HI), and starch yield at 360 days after planting (DAP) of six cassava genotypes under two water treatments in 2021/2022 growing season.

Treatment	Storage root fresh weight (t ha^{-1})	Storage root dry weight (t ha^{-1})	Total dry weight (t ha^{-1})	HI	Starch yield (t ha^{-1})
Water treatment (W)					
Drought (W1)	26.5	9.8A	12.8A	0.77A	250.2A
Irrigation (W2)	24.6	8.0B	11.9B	0.68B	192.0B
F-test	NS	**	*	**	**
C.V. (%)	10.89	8.74	7.04	2.36	9.52
Genotype (G)					
Kasetsart 50 (G1)	23.7C	9.1B	13.4A	0.67D	249.0A
Rayong 9 (G2)	22.1D	8.0C	11.3C	0.71C	212.8B
Rayong 72 (G3)	29.6A	10.1A	12.7B	0.80A	252.3A
CMR38-125-77 (G4)	25.5B	9.7AB	12.5B	0.78AB	260.8A
CMR35-91-63 (G5)	24.0BC	8.4C	11.1C	0.75B	223.5B
CM523-7 (G6)	28.2A	8.3C	13.1AB	0.64E	128.0C
F-test	**	**	**	**	**
G x W					
W1 x G1	22.6EF	10.3B	13.9BC	0.73D	296.7A
W1 x G2	25.1CD	9.2B-D	11.1EF	0.83A	254.5B
W1 x G3	29.6A	10.3B	12.7D	0.81A	285.6A
W1 x G4	29.5AB	11.4A	15.1A	0.76B-D	309.7A
W1 x G5	25.4CD	9.0C-E	11.9DE	0.76B-D	218.8C
W1 x G6	26.5BC	8.6D-F	11.9DE	0.73D	135.8E
W2 x G1	24.7C-E	8.0EF	12.9CD	0.61E	201.3C
W2 x G2	19.1G	6.7G	11.4E	0.59EF	171.1D
W2 x G3	29.6A	10.0BC	12.7D	0.79A-C	219.1C
W2 x G4	21.5F	7.9F	9.9G	0.80AB	211.9C
W2 x G5	22.7D-F	7.7FG	10.2FG	0.75CD	228.2BC
W2 x G6	29.8A	8.0EF	14.4AB	0.56F	120.3E
F-test	**	**	**	**	**
C.V. (%)	5.82	8.07	5.46	4.09	8.92

Note: Different letters in the same column represent significant differences (least significant difference test). NS, *, ** = non-significant, significant at $p \leq 0.05$ and significant at $p \leq 0.01$ level, respectively.

Table 5 (on next page)

Means for leaf growth rate (LGR), stem growth rate (SGR), and storage root growth rate (SRGR) during 90–150, 150–180, and 180–360 days after planting (DAP) of six cassava genotypes under two water regimes in the 2022/2023 growing season.

Each data point indicates the average performance of six cassava genotypes under two water regimes in the 2022/2023 growing season.

Table 5:

Means for leaf growth rate (LGR), stem growth rate (SGR), and storage root growth rate (SRGR) during 90–150, 150–180, and 180–360 days after planting (DAP) of six cassava genotypes under two water regimes in the 2022/2023 growing season.

Treatment	LGR (g day^{-1})			SGR (g day^{-1})			SRGR (g day^{-1})		
	90–150 DAP	150–180 DAP	180–360 DAP	90–150 DAP	150–180 DAP	180–360 DAP	90–150 DAP	150–180 DAP	180–360 DAP
Water treatment (W)									
Drought (W1)	1.01A	0.32B	0.21A	0.3B	2.5B	0.4B	1.6A	4.4A	2.8B
Irrigation (W2)	0.95B	0.73A	0.13B	0.6A	7.0A	0.5A	1.1B	2.6B	3.6A
F-test	*	**	**	**	**	**	**	**	**
C.V. (%)	5.08	17.51	11.01	24.50	24.45	8.48	10.53	20.12	15.39
Genotype (G)									
Kasetsart 50 (G1)	1.32B	0.50B	0.07D	0.2D	6.9A	0.4C	0.8E	4.4B	2.1D
Rayong 9 (G2)	0.64E	0.30C	0.21AB	0.3C	1.7D	0.6B	0.6E	2.2D	2.3CD
Rayong 72 (G3)	0.79D	0.33C	0.23A	0.8A	2.7C	0.6B	2.5A	3.7C	1.3E
CMR38-125-77 (G4)	1.63A	0.60B	0.16C	0.5B	6.6A	0.2D	2.1B	2.1D	3.6B
CMR35-91-63 (G5)	0.99C	0.95A	0.15C	0.3C	6.7A	0.7A	1.0D	6.3A	7.0A
CM523-7 (G6)	0.52F	0.49B	0.19B	0.7A	4.0B	0.2D	1.3C	2.1D	2.7C
F-test	**	**	**	**	**	**	**	**	**
G x W									
W1 x G1	2.02B	0.18E	0.06EF	0.2DE	3.0E	0.3E	1.2D	6.0BC	1.6F
W1 x G2	0.24G	0.45C	0.26C	0.2DE	1.0FG	0.7C	0.6FG	3.3D	1.5F
W1 x G3	0.14G	0.19E	0.43A	0.1G	0.1G	0.9B	4.5A	6.5B	0.4G
W1 x G4	2.74A	0.27DE	0.04FG	0.5C	4.5CD	0.1G	1.2D	1.3F	4.0C
W1 x G5	0.50EF	0.43CD	0.14D	0.1G	3.5DE	0.4E	0.8EF	7.6A	7.5A
W1 x G6	0.45F	0.43CD	0.32B	0.7B	2.9E	0.2F	1.6C	1.6EF	1.6F
W2 x G1	0.63E	0.81B	0.08E	0.1G	10.8A	0.5D	0.4G	2.8D	2.6DE
W2 x G2	1.04D	0.16E	0.16D	0.3D	2.4EF	0.5D	0.7E-G	1.2F	3.1CD
W2 x G3	1.43C	0.47C	0.02G	1.4A	5.4C	0.3E	0.4G	0.9F	2.1EF
W2 x G4	0.50EF	0.93B	0.28C	0.5C	8.7B	0.3E	3.0B	2.8D	3.3CD
W2 x G5	1.49C	1.47A	0.16D	0.4C	9.8A	1.1A	1.3CD	5.0C	6.4B
W2 x G6	0.59EF	0.54C	0.07EF	0.8B	5.2C	0.3E	1.0DE	2.6DE	3.8C
F-test	**	**	**	**	**	**	**	**	**
C.V. (%)	11.57	21.29	10.46	16.48	14.75	7.83	12.77	15.22	14.53

Note: Different letters in the same column represent significant differences (least significant difference test). ** = significant at $p \leq 0.01$ level, respectively.

Table 6(on next page)

Means for crop growth rate (CGR) and relative growth rate (RGR) of six cassava genotypes under two water treatments in the 2022/2023 growing season.

Each data point indicates the average performance of six cassava genotypes under two water treatments in the 2022/2023 growing season.

Table 6:

Means for crop growth rate (CGR) and relative growth rate (RGR) of six cassava genotypes. under two water treatments in the 2022/2023 growing season.

Treatment	CGR (g m^{-2} day^{-1})			RGR x 10^{-2} (g day^{-1})	
	90–150 DAP	150–180 DAP	180–360 DAP	90–150 DAP	150–360 DAP
Water treatment (W)					
Drought (W1)	1.7B	31.0B	7.2A	0.58	0.87A
Irrigation (W2)	2.8A	38.3A	2.6B	0.62	0.66B
F-test	**	**	**	NS	**
C.V. (%)	7.42	0.50	3.43	7.74	11.13
Genotype (G)					
Kasetsart 50 (G1)	1.0E	28.6C	5.2C	0.49C	0.78B
Rayong 9 (G2)	1.7D	21.0D	7.1A	0.12E	0.77BC
Rayong 72 (G3)	1.0E	17.0E	6.5B	0.35D	0.89A
CMR38-125-77 (G4)	3.6B	42.0B	3.5D	0.48C	0.71C
CMR35-91-63 (G5)	4.4A	71.7A	0.7E	1.41A	0.57D
CM523-7 (G6)	2.1C	27.6C	6.3B	0.74B	0.87A
F-test	**	**	**	**	**
G x W					
W1 x G1	0.8F	18.2G	8.3C	0.72D	0.81C-E
W1 x G2	0.2G	19.0G	9.5B	0.04H	0.83B-D
W1 x G3	0.4G	10.3H	12.0A	0.18G	0.71F
W1 x G4	3.7B	40.3D	5.2E	0.73D	1.11A
W1 x G5	2.7D	75.1A	0.7G	0.85C	0.85BC
W1 x G6	2.5D	23.0F	7.3D	0.96B	0.90B
W2 x G1	1.1F	39.0D	2.2F	0.25F	0.72D-F
W2 x G2	3.1C	22.9F	4.6E	0.20FG	0.73D-F
W2 x G3	1.5E	23.7F	1.0G	0.51E	0.72EF
W2 x G4	3.4C	43.7C	1.8F	0.23FG	0.66F
W2 x G5	6.1A	68.3B	0.7G	1.98A	0.28G
W2 x G6	1.7E	32.2E	5.2E	0.52E	0.83BC
F-test	**	**	**	**	**
C.V. (%)	8.77	3.46	10.34	6.65	7.76

Note: Different letters in the same column represent significant differences (least significant difference test). NS, ** = non-significant and significant at $p \leq 0.05$, respectively.

Table 7(on next page)

Means for storage root fresh weight, storage root dry weight, total dry weight, harvest index (HI), and starch yield at 360 days after planting (DAP) of six cassava genotypes under two water treatments in the 2022/2023 growing season .

Each data point indicates the average performance of six cassava genotypes under two water treatments in the 2022/2023 growing season .

Table 7:

Means for storage root fresh weight, storage root dry weight, total dry weight, harvest index (HI), and starch yield at 360 days after planting (DAP) of six cassava genotypes under two water treatments in the 2022/2023 growing season.

Treatment	Storage root fresh weight ($t\ ha^{-1}$)	Storage root dry weight ($t\ ha^{-1}$)	Total dry weight ($t\ ha^{-1}$)	HI	Starch yield ($t\ ha^{-1}$)
Water treatment (W)					
Drought (W1)	26.3A	9.8A	13.3A	0.76A	265.2A
Irrigation (W2)	24.1B	6.9B	10.2B	0.68B	176.6B
F-test	**	**	**	*	**
C.V. (%)	2.88	7.14	6.24	8.57	5.63
Genotype (G)					
Kasetsart 50 (G1)	22.9D	8.6BC	11.7B	0.78A	249.9A
Rayong 9 (G2)	20.9E	8.0C	11.7B	0.71BC	213.7B
Rayong 72 (G3)	30.1A	6.9D	10.1C	0.65D	198.0C
CMR38-125-77 (G4)	25.9C	9.7A	12.9A	0.75AB	245.1A
CMR35-91-63 (G5)	23.4D	8.7B	12.3AB	0.70C	210.8B
CM523-7 (G6)	27.9B	8.4BC	11.7B	0.72BC	207.8EC
F-test	**	**	**	**	**
G x W					
W1 x G1	21.8D	9.6BC	12.8BC	0.80A	309.0A
W1 x G2	24.3C	9.2CD	13.4B	0.76AB	247.0C
W1 x G3	29.6A	10.3B	13.4B	0.77AB	280.6B
W1 x G4	30.4A	11.4A	14.9A	0.77AB	296.8A
W1 x G5	25.8B	9.6BC	13.3B	0.73BC	259.7C
W1 x G6	25.9B	8.7DE	11.9CD	0.73BC	198.0E
W2 x G1	24.1C	7.6FG	10.6EF	0.75AB	190.8EF
W2 x G2	17.5E	6.7G	10.0F	0.67C	180.3F
W2 x G3	30.5A	3.5H	6.8G	0.53D	115.4H
W2 x G4	21.5D	7.9EF	10.9D-F	0.72BC	193.5EF
W2 x G5	21.0D	7.7F	11.4DE	0.67C	161.8G
W2 x G6	29.8A	8.1EF	11.4DE	0.71BC	217.5D
F-test	**	**	**	**	**
C.V. (%)	3.41	7.41	6.61	5.65	4.66

Note: Different letters in the same column represent significant differences (least significant difference test). *, ** = significant at $p \leq 0.05$ and significant at $p \leq 0.01$ level, respectively.

Figure 1

Weather data at the Field Crop Research Station of Khon Kaen University, Khon Kaen, Thailand for the experiment from August 2021 to August 2022 and from August 2022 to August 2023. (A) 2021/2022 and (B) 2022/2023.

Weather data at the Field Crop Research Station of Khon Kaen University, Khon Kaen, Thailand.

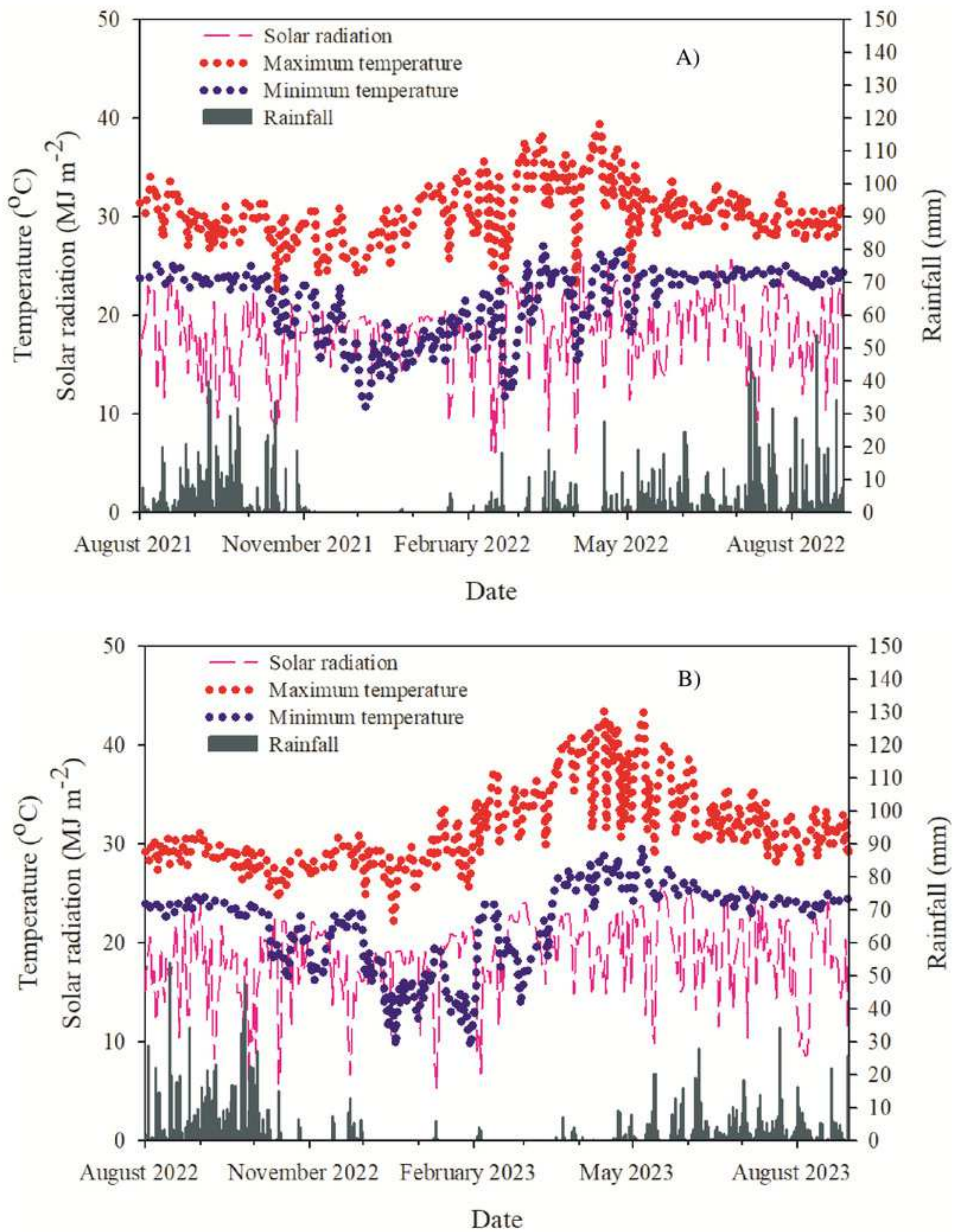

Figure 1: Weather data at the Field Crop Research Station of Khon Kaen University, Khon Kaen, Thailand for the experiment from August 2021 to August 2022 and from August 2022 to August 2023. (A) 2021/2022 and (B) 2022/2023.

Figure 2

Soil moisture content of rainfed treatment (drought treatment) and irrigation treatment. (A) soil depth 0–30 cm in 2021/2022. (B) 30–60 cm in 2021/2022. (C) 0–30 cm in 2022/2023. (D) 30–60 cm in 2022/2023.

Soil moisture content of rainfed treatment (drought treatment) and irrigation treatment.

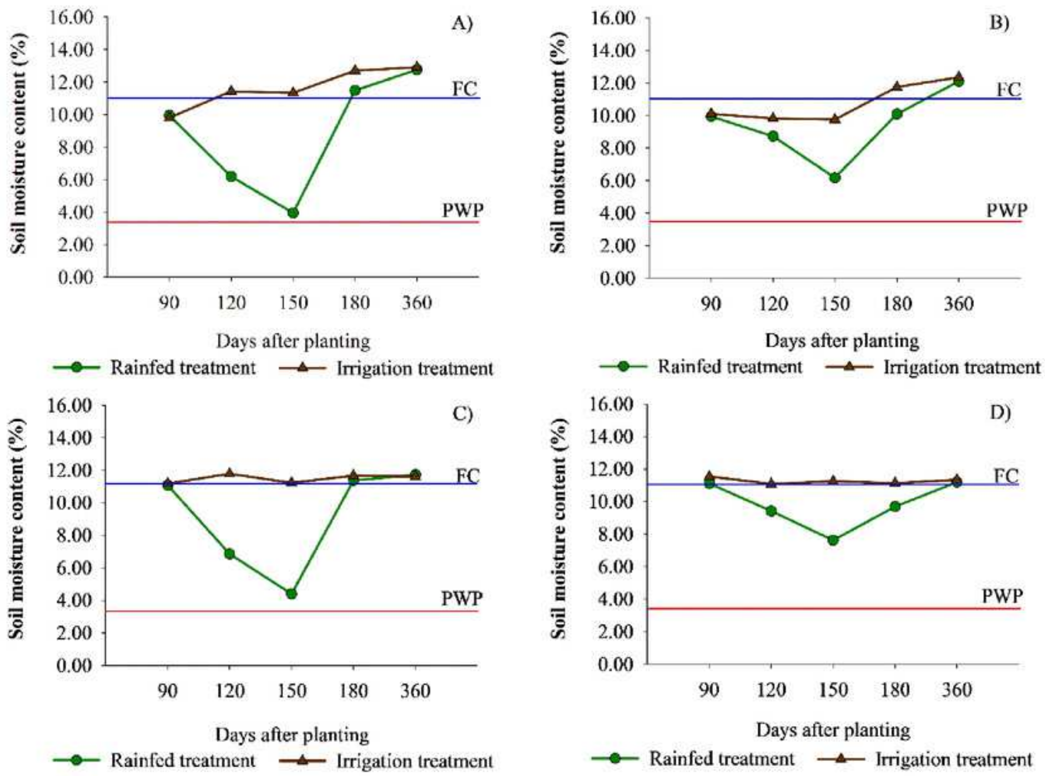

Figure 2: Soil moisture content of rainfed treatment (drought treatment) and irrigation treatment. (A) soil depth 0–30 cm in 2021/2022. (B) 30–60 cm in 2021/2022. (C) 0–30 cm in 2022/2023. (D) 30–60 cm in 2022/2023.

Figure 3

Relative water content (%) at 90, 120, 150, 180, and 360 days after planting (DAP) for drought and irrigation treatment. (A) during 2021/2022 and (B) 2022/2023. Different letters in the same days after planting represent significant differences (lea

Relative water content (%) at 90, 120, 150, 180, and 360 days after planting (DAP) for drought and irrigation treatment.

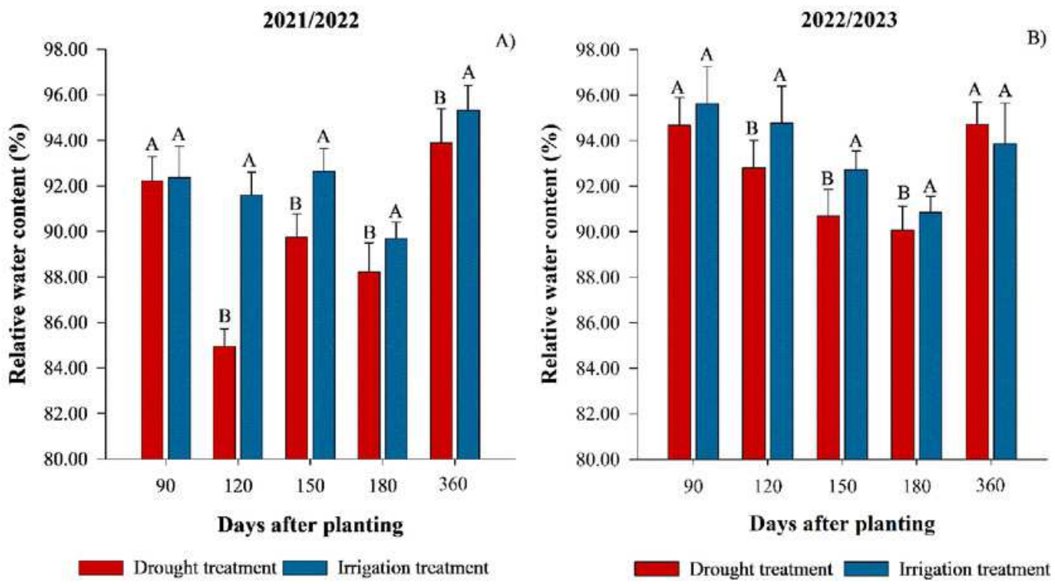

Figure 3: Relative water content (%) at 90, 120, 150, 180, and 360 days after planting (DAP) for drought and irrigation treatment. (A) during 2021/2022 and (B) 2022/2023. Different letters in the same days after planting represent significant differences (least significant difference test).

Figure 4

Relative water content (%) at 90, 120, 150, 180, and 360 days after planting (DAP) for six cassava genotypes . (A) during 2021/2022 and (B) 2022/2023. Different letters in the same days after planting represent significant differences (least signific

Relative water content (%) at 90, 120, 150, 180, and 360 days after planting (DAP) for six cassava genotypes .

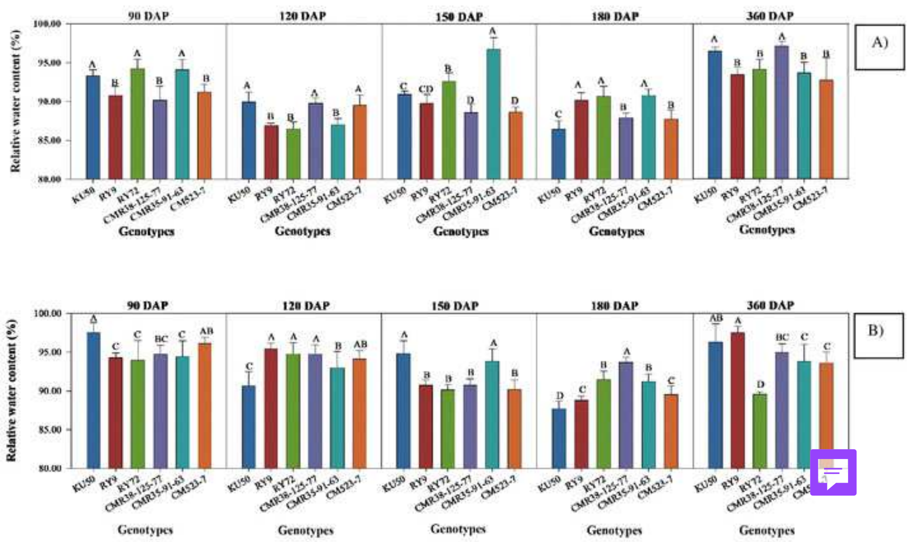

Figure 4: Relative water content (%) at 90, 120, 150, 180, and 360 days after planting (DAP) for six cassava genotypes. (A) during 2021/2022 and (B) 2022/2023. Different letters in the same days after planting represent significant differences (least significant difference test).