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Research Article
Supplementary Irrigation for Cassava Planted in the Late Rainy Season of Northeastern Thailand

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Abstract

Background and Objective: Cassava planting usually takes place in the latter part of the rainy season, which thereby exposes the cassava to the prolonged drought of the upcoming dry season. The objective of this research was to investigate the effects of irrigation regimes on growth, yield and starch content of cassava. **Materials and Methods:** Two cassava varieties were planted in split-plot design, late in the rainy season of 2014/2015. Cassava varieties (Huaybong 80 and Rayong 11) were assigned as the main-plot. Sub-plots were cultivated with 5 different water regimes: (1) The crop received 15 mm of water when the daily cumulative pan evaporation value reached 40 mm [I-15, EV-40 mm] and, correspondingly, (2) [I-15, EV-60 mm], (3) [I-30, EV-40 mm], (4) [I-30, EV-60 mm] and (5) The no-irrigation (control) group [I-0]. All treatments received similar amounts of natural rainfall during the rainy season. One way-analysis of variance (ANOVA) was performed according to a split plot design using statistics version 8 (STAT 8) software. Means were separated by Least Significant Difference (LSD) at 0.05 probability level. **Results:** Irrigation treatments in each of the irrigated sub plots significantly increased the storage root yields over the non-irrigated control across the two varieties ($p \leq 0.01$). Total water usage (in descending order) of 1363, 1153, 1108, 1003 and 853 mm were recorded for sub-plots (3) [I-30, EV-40 mm], (4) [I-30, EV-60 mm], (1) [I-15, EV-40 mm], (2) [I-15, EV-60 mm] and (5) [I-0], respectively. The water use efficiency determined within cropping season ranged from 62.8-74.7 kg ha^{-1} mm^{-1}. Percentages of total water applied from total water used in sub-plots (3) [I-30, EV-40 mm], (4) [I-30, EV-60 mm], (1) [I-15, EV-40 mm] and (2) [I-15, EV-60 mm] were 37.4, 26.0, 23.0 and 14.9%, respectively. **Conclusion:** The water regime of [I-30, EV-40 mm] (sub-plot 3) produced the highest fresh (85.6 t ha^{-1}) and dry (37.5 t ha^{-1}) storage root yields across both varieties; however, the Huaybong 80 variety produced significantly higher storage root yields than those of the Rayong 11 variety across all irrigation regimes ($p \leq 0.05$). Neither the irrigation regime nor the variety of cassava had any significant effect on the starch content of the storage root.

Key words: Cassava, growth, yield, starch contents, drip irrigation, water use efficiency

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Northeastern Thailand has a semi-humid tropical climate, which is characterized by rainy (May-October) and dry (November-April) seasons[1]. Rainfed agriculture dominates this region, comprising approximately 80% of the total agricultural land area. The amount of actual evapotranspiration is larger than that of all rainfall in the dry season.

Cassava is a cash crop of small holding farmers in Northeastern Thailand. Planted over the 8 months period that contains both the dry and rainy seasons, cassava planting usually takes place in the later stage of the rainy season, which provides residual soil moisture. Given this situation, the cassava will be exposed to prolonged drought in the dry season. The cassava growth cycle is typically interrupted by 3-6 months of drought, influencing various physiological processes; resulting in depressed growth, development and economic yield[2].

In recent years, there has been a tremendous increase in research efforts made to improve production through breeding drought-tolerant varieties, nutrient management and crop establishment[3-6]. Noticeably, the possibility of increasing cassava production per land area unit under cultivation through supplemental irrigation, especially during the rainless period, has not been fully explored.

Drip irrigation has proved to be successful in terms of water usage and increased yield, as well as improved product quality[7]. As water is applied close to the plant root zone, the losses caused though drainage or by wetting inter-rows and ridges are minimized and the soil is maintained continuously in a condition which is highly favorable to crop growth[8]. The objective of this study was therefore to examine water use, growth and yield of cassava planted in the late rainy season and cultivated under different water regimes during the dry season, using drip irrigation technology.

MATERIALS AND METHODS

Location of field experiment: The study was conducted at the Agronomy Experimental Farm of Khon Kaen University, Khon Kaen, Thailand (lat. 16°28/N, long. 102°48/E, 200 m AMSL). Northeast Thailand is characterized by a tropical climate, characterized by distinct wet and dry seasons. The soil texture of the experimental field is loamy sand, containing pH 5.36, organic matter 0.42%, total N 0.020%, available P 51.99 mg kg^{-1} and exchangeable K 53.48 mg kg^{-1}.

Experimental design and treatments: The experiments were laid out in split plot design with 4 replications. Main plots consisted of two cassava varieties (Huaybong 80 and Rayong 11). Five different water regimes based on daily cumulative pan evaporation value were applied to the sub-plots, as mentioned in Table 1.

Lateral drip irrigation was laid out at 100 cm spacing between rows. Drippers were placed at 100 cm apart along the lateral line and meters were installed to determine the quantity of water used in each treatment.

Cultural practices: The experimental field was thoroughly ploughed, 2 times, by 3-disk and 7-disk tractors, forming 40 cm high ridges. The rows and cassava plants were spaced (1×1 m) apart. Each plot (4×6 m) was separated by a 2 m wide space for demarcation between plots; totaling 40 plots, including the control treatment. Two hand weeding was undertaken one Month After Planting (MAP). Stem cuttings 15 cm long were inserted vertically into the soil on the top of the ridges. Granule fertilizer (grade 15-7-18 [N, P_2O_5, K_2O] at rate of 156 kg ha^{-1}) was applied to all treatments, one MAP, post weeding. Crops were planted using residual soil moisture for germination and initial growth. Initial irrigation treatments were applied based on daily cumulative pan evaporation, as assigned for each sub-plot treatment. The experiment was conducted from 30 October 2015-6 October 2016.

Data collection: Fibrous root dry weight was taken from five sample plants for each treatment at 30 and 120 Days After Planting (DAP). An additional five plants from each treatment were selected at random outside the harvesting area at 120, 240 and 340 DAP; to determine the number of storage roots, leaf area and storage root weight per plant. After the number of storage roots per plant was recorded, the plants were separated into leaf, stem and root. The leaf area was determined through an automatic leaf area meter (model AAC-400). Leaf Area Index (LAI) was computed by examining the leaf area per plant within the ground area covered. Harvest Index (HI) was determined by calculating the storage root dry weight divided by total plant dry weight. Starch content (%) was determined using the Riemann balance method.

Leaf samples were taken at 80, 105, 142 and 177 DAP outside the harvesting area to determine their Relative Water Content (RWC). The fourth fully-expanded leaf from the top of each plant within each sub-plot were sampled, along with twenty leaf disks (1.5 cm wide×2.0 cm long) which was excised from the middle of the center lobe (avoiding the midrib), weighed, placed in a petri dish of distilled water for 4 h, re-weighed to determine Hydrate Weight (HW) and then dried at 60°C for 48 h to determine the Dry Weight (DW). RWC was then calculated by dividing the difference between the Fresh Weight (FW) and Dry Weight (DW) by the difference between the Hydrate Weight (HW) and Dry Weight (DW). Data

Table 1: Irrigation treatments, water allotments and designations

Irrigation treatments	Water allotments	Designations
Sub plot (1)	The crop received 15 mm of water when the daily cumulative pan evaporation value reached 40 mm	[I-15, EV-40 mm]
Sub plot (2)	The crop received 15 mm of water when the daily cumulative pan evaporation value reached 60 mm	[I-15, EV-60 mm]
Sub plot (3)	The crop received 30 mm of water when the daily cumulative pan evaporation value reached 40 mm	[I-30, EV-40 mm]
Sub plot (4)	The crop received 30 mm of water when the daily cumulative pan evaporation value reached 60 mm	[I-30, EV-60 mm]
Sub plot (5)	The no-irrigation (control) group	[I-0]

All treatments received similar amounts of natural rainfall during the rainy season

were analyzed using analysis of variance procedures and the Least Significant Difference (LSD) was used to compare treatment methods (when the F-test proved significant at $p \leq 0.05$ or 0.01 level).

Weather data was recorded in an open field at a distance of 150 m from the experimental field. The values of pan evaporation, maximum and minimum air temperatures, solar radiation, relative humidity and rainfall are presented in Table 1. The soil moisture content was determined by gravimetric measurement at 0-15 cm depth at seven day intervals during the dry season (Fig. 1). Soil moisture content was calculated[9] using Eq. 1:

$$\% \text{ Moisture} = \frac{\text{(Wet soil weight)-(oven-dry soil weight)}}{\text{Oven-dry soil weight}} \times 100 \quad (1)$$

Statistical analysis: Data were analyzed statistically according to one-way analysis of variance (ANOVA) procedures using statistix version 8 (STAT 8) software (Analytical software, USA) to test the significant ($p \leq 0.05$) for single factors and interactions for split plot design (Statistix Analytical Software)[10].

RESULTS

Weather conditions: The rainfall, pan evaporation, maximum and minimum temperatures, sunlight and relative humidity measured throughout our experiment are shown in Table 2. Total rainfall was 853 mm, of which 103 mm occurred in dry season (November through April). Throughout the cropping season, the mean daily maximum temperature ranged from 29.9-37.9°C, while the mean daily minimum temperature ranged from 18.1-26.1°C. The highest maximum temperature was recorded in May, whereas the lowest minimum temperature was experienced in December. The mean daily pan evaporation rate varied from 3.52-7.13 mm day^{-1}. The highest rate of pan evaporation was observed in May. The mean daily relative humidity ranged from 82-92%. The highest relative humidity was recorded in September. The mean sunlight varied from 3.38-9.04 h day^{-1}. The greatest amount of sunlight was recorded in January, whereas the lowest was experienced in September.

Soil moisture content: The soil moisture content (at a depth of 0-15 cm) in the irrigation controlled sub-plots gradually decreased below the Permanent Wilting Point (PWP) at 50 DAP and at 100 DAP in the no irrigation (control) treatment sub-plot. Furthermore, the soil moisture content rose in the dry season, due to the previous summer rain (Fig. 1). And, in all irrigation treatments, the soil moisture content stayed within the available ranges of Field Capacity (FC) and their respective Permanent Wilting Points (PWP). We may extrapolate, that the difference in soil moisture content between each sub-plot depends upon the amount of water provided in each irrigation treatment.

Fibrous root growth: All irrigation treatments significantly increased the fibrous root dry weight ($p \leq 0.01$) over the non-irrigated control across both varieties at 120 DAP, yet demonstrated no significant effect at 30 DAP, as shown in Table 2. The highest fibrous root dry weight occurred in the sub-plot (3) [I-30, EV-40 mm] treatment. The Rayong 11 variety garnered higher fibrous root dry weights than those of the Huaybong 80 variety.

Leaf growth: The Leaf Area Index (LAI) was significantly affected by irrigation treatments across both varieties at 120 ($p \leq 0.01$), 240 ($p \leq 0.05$) and 340 ($p \leq 0.01$) DAP (Table 3). The highest LAI was observed in the sub-plot (3) [I-30, EV-40 mm] treatment at 120, 240 and 340 DAP. In the present experiment, LAI continued to increase after planting and subsequently decreased at 340 DAP, due to leaf shedding caused by drought at the end of rainy season. Supplementary irrigation was undertaken only in the dry season.

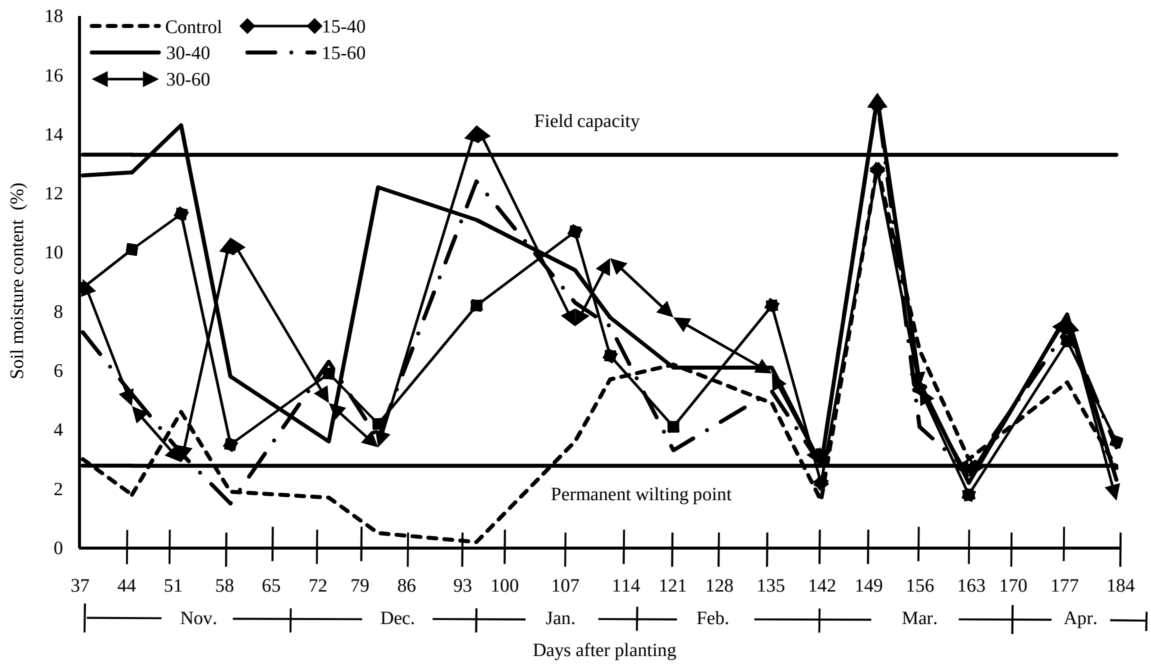

Fig. 1: Soil moisture content (%) at 0-15 cm soil depth of the different irrigation regimes during the dry season (November, 2014-April, 2015)

Table 2: Weather data of the experimental site during the 2014/2015 cropping season

Month	Rainfall (mm)	Evaporation (mm day^{-1})	Sunlight (h day^{-1})	Temperature (°C) Maximum	Minimum	Relative humidity (%)
Oct. 2014	50.7	4.21	7.68	29.9	22.9	84
Nov. 2014	6.4	4.40	7.64	32.8	23.1	88
Dec. 2014	0.0	4.93	8.27	30.0	18.1	84
Jan. 2015	29.2	4.69	9.04	29.9	15.2	83
Feb. 2015	0.0	4.90	7.68	32.4	18.5	86
Mar. 2015	13.8	5.91	8.02	35.9	24.2	83
Apr. 2015	23.6	6.71	7.55	36.2	24.0	78
May.2015	25.9	7.13	8.04	37.9	16.1	82
Jun. 2015	112.8	5.94	6.46	36.0	25.2	85
Jul. 2015	131.8	5.52	4.48	33.6	25.1	89
Aug. 2015	301.7	4.14	4.58	32.6	24.2	91
Sept. 2015	80.2	3.52	3.38	32.8	24.6	92
Oct. 2015	46.9	3.83	7.64	31.7	23.2	89
Total	853.0	65.83	90.46	431.7	294.4	1114
Mean	65.6	5.06	6.96	33.2	22.2	86

Storage root number per plant: The irrigation treatments (sub-plots 1-4) significantly increased the number of storage roots per plant ($p \leq 0.01$) and the storage root dry weight per plant in the control (non-irrigated sub-plot 5) across both varieties at 120, 240 and 340 DAP (Table 3). The maximum number of storage roots per plant was obtained in sub-plot (3) [I-30, EV-40 mm] at 120, 240 and 340 DAP. Across all irrigation regimes, the Huagbong 80 produced a significantly higher ($p \leq 0.05$) number of storage roots per plant than those of Rayong 11 harvest (Table 4).

Storage root fresh weight per plant: All irrigation treatments significantly increased the storage root fresh weight per plant ($p \leq 0.01$) over the non-irrigated treatment across both varieties at 120, 240 and 340 DAP (Table 4). The highest storage root fresh weight per plant was obtained in the sub-plot (1) [I-15, EV-40 mm] treatment. Storage root fresh weight per plant differed significantly between the two varieties across each irrigation regime at 120 ($p \leq 0.01$), 240 ($p \leq 0.05$) and 340 ($p \leq 0.01$) DAP. The maximum storage root fresh weight per plant was observed in the Huaybong 80 variety.

Table 3: Effects of each irrigation regime and variety on fibrous root DW and LAI of cassava planted in the late rainy season of 2014/2015

	Root dry weight (g plant^{-1})		Leaf area index		
Treatment	30 DAP	120 DAP	120 DAP	240 DAP	340 DAP
Variety (V)					
Huaybong 80	0.207	0.561^{b}	0.60	4.79	0.92
Rayong 11	0.128	0.682^{a}	0.57	5.38	1.19
Irrigation regime (I)					
I-15,40 mm	0.189	0.691^{a}	0.64^{ab}	5.45^{a}	1.12^{a}
I-15,60 mm	0.155	0.604^{a}	0.53^{ab}	4.84^{ab}	1.08^{a}
I-30,40 mm	0.205	0.754^{a}	0.67^{a}	5.77^{a}	1.20^{a}
I-30,60 mm	0.180	0.728^{a}	0.65^{a}	5.59^{a}	1.19^{a}
I-0	0.108	0.330^{b}	0.43^{c}	3.77^{b}	0.97^{b}
F-test					
V	ns	0	ns	ns	ns
I	ns	**	**	0	**
V×I	ns	ns	ns	ns	ns

Means followed by the same letter in the same column were not significantly different than the LSD (p<0.05), *Significant at p<0.05, **Significant at p<0.01, ns = Not significant

Table 4: Effects of each irrigation regime and variety on both storage root number and storage root fresh weight of cassava planted in the late rainy season of 2014/2015

	Storage root number per plant			Storage root fresh weight (kg plant^{-1})		
Treatment	120 DAP	240 DAP	340 DAP	120 DAP	240 DAP	340 DAP
Variety (V)						
Huaybong 80	10.2^{a}	12.5^{a}	14.7^{a}	0.85^{a}	3.4^{a}	9.2^{a}
Rayong 11	8.1^{b}	10.1^{b}	12.7^{b}	0.52^{b}	2.6^{b}	6.4^{b}
Irrigation regime (I)						
I-15,40 mm	10.9^{a}	11.4^{b}	13.7^{bc}	0.83^{ab}	3.1^{ab}	7.9^{a}
I-15,60 mm	8.6^{b}	11.2^{b}	13.0^{c}	0.71^{b}	2.9^{b}	7.5^{a}
I-30,40 mm	11.8^{a}	13.4^{a}	15.7^{ab}	0.86^{a}	3.8^{a}	8.8^{a}
I-30,60 mm	10.6^{ab}	13.8^{a}	16.3^{a}	0.85^{a}	3.5^{ab}	8.7^{a}
I-0	4.4^{c}	6.8^{c}	9.8^{d}	0.17^{c}	1.8^{c}	5.7^{b}
F-test						
V	**	0	0	**	0	**
I	**	**	**	**	**	**
V×I	ns	ns	ns	ns	ns	0

Means followed by the same letter in the same column were not significantly different than the LSD (p<0.05), *Significant at p<0.05, **Significant at p<0.01, ns = Not significant

Table 5: Effects of each irrigation regime and variety on fresh storage root yield, dry storage root yield, starch content percentage and harvest index of cassava planted in the late rainy season of 2014/2015

	Storage root yield (t ha^{-1})			
Treatment	Fresh weight	Dry weight	Starch content (%)	Harvest Index (HI)
Variety (V)				
Huaybong 80	92.5^{a}	35.6^{a}	29.4	0.64^{a}
Rayong 11	60.6^{b}	25.6^{b}	27.4	0.59^{b}
Irrigation regime (I)				
I-15,40 mm	79.2^{ab}	31.9^{ab}	29.2	0.63^{a}
I-15,60 mm	74.9^{b}	30.6^{b}	27.9	0.61^{ab}
I-30,40 mm	85.6^{a}	37.5^{a}	29.0	0.65^{a}
I-30,60 mm	54.6^{a}	35.1^{ab}	29.1	0.63^{a}
I-0	51.1^{c}	19.4^{c}	27.0	0.58^{b}
F-test				
V	0	0	ns	0
I	**	0	ns	0
V×I	ns	ns	ns	ns

Means followed by the same letter in the same column were not significantly different than the LSD (p<0.05), *Significant at p<0.05, **Significant at p<0.01, ns = Not significant

Storage root yield and starch content: The irrigation treatments (sub-plots 1-4) significantly increased the fresh storage root yield ($p \leq 0.01$) and dry storage root yield ($p \leq 0.05$) over the non-irrigated control (Table 5). However, the fresh storage root yield did not significantly differ among the [I-30, EV-40 mm], [I-30, EV-60 mm] and [I-15, EV-40 mm]

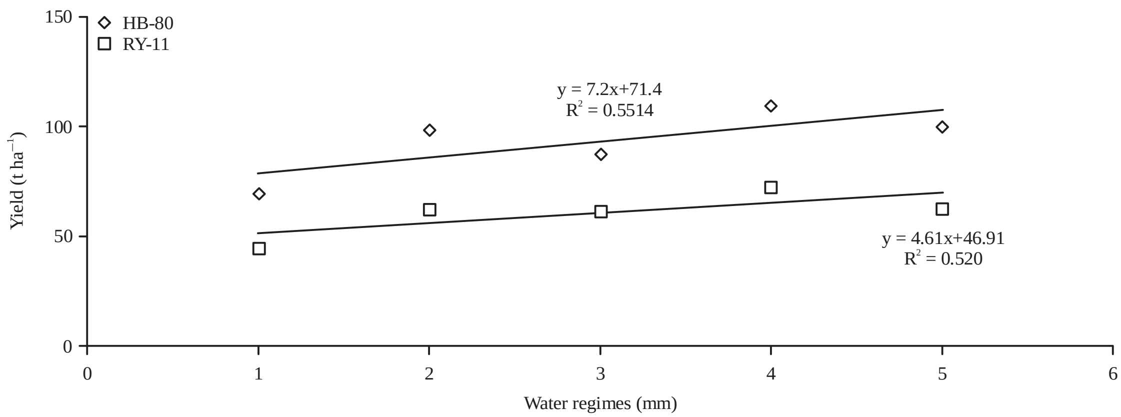

Fig. 2: Linear regression between water regimes and storage root yield of two cassava varieties
(1 = 853 mm, 2 = 1108 mm, 3 = 1003 mm, 4 = 1363 mm and 5 = 1153 mm)

Table 6: Effects of each irrigation regime and variety on relative water content of cassava leaves planted in late rainy season of 2014/2015

	Relative water content (%)			
Treatment	80 DAP	105 DAP	142 DAP	177 DAP
Variety (V)				
Huaybong 80	68.7	66.2	67.8	65.5
Rayong 11	67.3	64.4	66.2	65.2
Irrigation regime (I)				
I-15,40 mm	68.4^{abc}	66.0	66.9	64.3
I-15,60 mm	66.9^{bc}	65.7	66.3	65.9
I-30,40 mm	70.0^{a}	66.6	67.7	65.2
I-30,60 mm	68.8^{ab}	65.6	67.7	65.1
I-0	65.9^{c}	63.6	66.5	66.2
F-test				
V	ns	ns	ns	ns
I	0	ns	ns	ns
V×I	ns	ns	ns	ns

Means followed by the same letter in the same column were not significantly different than LSD ($p<0.05$), *Significant at $p<0.05$, **Significant at $p<0.01$, ns = Not significant

treatments. The maximum fresh storage root yield and dry storage root yield were achieved in the sub-plot (3) [I-30, EV-40 mm] treatment. Across every irrigation regime, the Huaybong 80 variety produced significant higher fresh and dry storage root yields than those of the Rayong 11 variety ($p\leq 0.05$), (Table 5). In the present experiment, both the irrigation regime and variety produced no significant effect on starch contents of storage root at harvest (Table 5).

Relationship between water regimes and storage root yield: The coefficient of determination (R^2) was 0.520 and 0.551 in the Rayong 11 and Huaybong 80 varieties, respectively (Fig. 2). This demonstrates a positive correlation between the storage root yield and their corresponding water regime, indicating that the storage root yield increases as the application of water increases.

Harvest index and relative water content: Each irrigation treatment significantly increased the Harvest Index (HI) over the non-irrigation control ($p\leq 0.05$), ranging from 0.58-0.65; as illustrated in (Table 6). The highest HI value was obtained in the sub-plot (3) [I-30, EV-40 mm] treatment. Across all irrigation regimes, the Huaybong 80 variety scored significantly higher HI values and therefore greater efficiency of translocation of assimilates, than those of the Rayong 11 variety ($p\leq 0.05$).

Over the 2014/2015 dry season, each of the irrigation regimes had a significant effect on the Relative Water Content (RWC) in the cassava leaves of both varieties at 80 DAP ($p\leq 0.05$) but no effect after 105 DAP (Table 6). The lowest RWC (65.9%) was obtained in the non-irrigated [I-0] control treatment at 80 DAP, in which the maximum soil moisture content value fell below the Permanent Wilting Point (PWP), presented earlier in Fig. 1. Furthermore, rainfall

Table 7: Total water use and water use efficiency of each irrigation regime

Parameters	(1) $_{15,40\ mm}$	(2) $_{15,60\ mm}$	(3) $_{30,40\ mm}$	(4) $_{30,60\ mm}$	(5) $_{0\ mm}$
Irrigation water applied (mm)	255	150	510	300	0
Effective rainfall (mm)	853	853	853	853	853
Total water used (mm) (TWU)	1108	1003	1363	1153	853
Total applied water to TWU (%)	23.0	14.9	37.4	26.0	0.0
Storage root yield (kg ha^{-1})	79219	74918	85625	84625	57106
Water use efficiency (kg ha^{-1} mm^{-1})	71.49	74.69	62.82	73.39	66.95

during the early rainy season resulted in soil moisture contents (in all crops) above the PWP.

Water use efficiency: Water consumption in sub-plots (1) [I-15, EV-40 mm], (2) [I-15, EV-60 mm], (3) [I-30, EV-40 mm], (4) [I-30, EV-60 mm] and control treatment (5) [I-0] was 1108, 1003, 1363, 1153 and 853, respectively (Table 7). The values of Water Use Efficiency (WUE) ranged from 62.82-74.69 kg ha^{-1}. Drip irrigation in sub-plots (1), (2) and (4) increased the (WUE) by 7, 12 and 10%, respectively and decreased by 6%, compared to that of I-0 control. The percentages of total water applied this season ranged from 14.9-37.4%.

DISCUSSION

Each of the irrigation regimes, significantly increased the storage root yield over the non-irrigated control ($p \leq 0.01$); providing the irrigated plants with a higher fibrous root dry weight and leaf area index (Table 3) and number of storage roots per plant and storage root fresh weight per plant (Table 4) than those of the [I-0] control treatment; which experienced water stress at 50 through 100 DAP (Fig. 1). Subere *et al.*[11] reported that drought generally inhibits fibrous root growth and the degree of habitation, depending on genotype; in contrast to the findings of Vandegeer *et al.*[12].

Leaf development (LAI), observed from crop establishment (120 DAP) to crop mid-season (240 DAP), ranged from 3.8-5.8 depending on the water regime across both varieties (similar to the 'optimum LAI for maximum crop growth' [4.0-6.5] reported by Enyi[13]. Noticeably, a decrease in LAI was observed in the late season stage (340 DAP), displayed earlier in Table 2, due to the leaf shedding caused by drought. This result was similar to the initial experiments reported by Odubanjo *et al.*[14].

In the present experiment, each irrigation regime significantly increased the storage root number per plant and storage root fresh weight per plant ($p \leq 0.01$) over the non-irrigated control crop, due to the reality that irrigated plants produce a higher LAI than that of non-irrigated crops (as also reported by Odubanjo *et al.*[14]; Wunprasert *et al.*[15]; Sunitha *et al.*[16] and Mogaji *et al.*[17]). The results determined that the Huaybong 80 variety produced significantly higher $p \leq 0.05$ numbers of storage roots per plant and subsequently higher storage root yield, than those of the Rayong 11 variety (in all irrigation and non-irrigated treatments). However, this result is in contrast to the results reported by Polthanee *et al.*[18].

The positive correlation between water regimes and storage root yield (Fig. 2) led to the coefficients of determination (R^2) 0.551 and 0.520, for the Huaybong 80 and Rayong 11 varieties, respectively. This indicates that the Huaybong 80 adapts better to drought than the Rayong 11 variety.

The fresh storage root yield under each irrigation treatment determined the Water Use Efficiency (WUE) of each sub-plot. The irrigated crops consumed (in decreasing order) 1363, 1153, 1108, 1003 and 853 mm of water for the entire season, in sub-plots (3) [I-30, EV-40 mm], (4) [I-30, EV-60 mm], (1) [I-15, EV-40 mm], (2) [I-15, EV-60 mm] and (5) [I-0], respectively. The data indicated a gradual reduction in WUE with decreasing quantities of irrigation. The maximum WUE was recorded in sub-plot (2) [I-15, EV-60 mm] and the minimum WUE in sub-plot (3) [I-30, EV-40 mm]; 74.7 and 62.8%, respectively, compared to the rain fed crops. We may conclude that supplementary irrigation during the dry season increases cassava storage root yields and overall crop productivity. Our results are confirmed by the findings of Odubanjo *et al.*[14], in which WUEs were 14.8-61.7% higher under drip irrigation in their two experimental seasons.

Results further determined that the irrigation regimes had no significant effect on the starch content of storage roots at harvest ($p \leq 0.05$). Polthanee *et al.*[18]; Samutthong *et al.*[19]; as well as Sinworn and Duangpatra[20] came to the same conclusion. In contrast, Hular-Bograd *et al.*[21] reported a significantly higher starch content of cassava under irrigation than those without irrigation ($p \leq 0.05$).

CONCLUSION

Drip irrigation, in all water regimes, significantly increased the cassava's fresh storage root yield over the non-irrigated crops. This was due to the associated higher leaf area indexes and storage root numbers per plant within the irrigation treatments. The maximum storage root yield was obtained in the sub-plot (3) [I-30, EV-40 mm] treatment. However, the highest water use efficiency was observed in the [I-15, EV-60 mm] irrigation treatment of sub-plot (2). Irrigation regimes as well as the specific cassava variety had no significant effect upon the starch content of the storage roots at harvest; however, the Huaybong 80 variety produced significantly higher fresh and dry storage root yields than those of the Rayong 11 variety.

SIGNIFICANCE STATEMENTS

This study discovers the possible supplementary irrigation during the rainless period in the dry season to increase the root yield of cassava planted in the late rainy season. This study will help the researcher to uncover the appropriate water regime applied during the dry season as well as the suitable cassava variety to use for cultivation in the late rainy season.

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