Hindawi
International Journal of Agronomy
Volume 2023, Article ID 6843217, 9 pages
https://doi.org/10.1155/2023/6843217

Research Article

Effects of Watering Regimes and Planting Density on Taro (*Colocasia esculenta*) Growth, Yield, and Yield Components in Embu, Kenya

Joyce Wambui Njuguna,[1] **Anne N. Karuma**,[1] **Patrick Gicheru**,[2] **and Richard Onwonga**[1]

[1]*Department of Land Resource Management and Agricultural Technology, University of Nairobi, P.O. Box 29053-00625, Nairobi, Kenya*
[2]*Kenya Agricultural and Livestock Research Organization, P.O. Box 27-60100, Embu, Kenya*

Correspondence should be addressed to Joyce Wambui Njuguna; joycenjuguna20@gmail.com

Received 5 September 2022; Revised 16 March 2023; Accepted 17 March 2023; Published 1 April 2023

Academic Editor: Mohamed Addi

Taro (*Colocasia esculenta* (L.) Schott) is one of the most underutilized crops in sub-Saharan Africa and an important staple food in the tropics. Understanding its growth response under selected watering regimes and planting densities underpins this research. A study was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO), Embu Research Centre, during the long rains (LR) in 2021 and the short rains (SR) in 2021–2022. A factorial experiment with a split-plot layout arranged in a completely randomized block design was used. The main factor was the irrigation levels, while the subfactor was the planting density, with three replications. The three irrigation levels were at 100%, 60%, and 30% based on the field capacity (FC). The planting densities used were 0.5 m × 0.5 m (40,000 plants ha^{-1}), 1 m × 0.5 m (20,000 plants ha^{-1}), and 1 m × 1 m (10,000 plants ha^{-1}), representative of high, medium, and low planting densities, respectively. Time and season ($P < 0.05$) significantly influenced taro growth components (plant height, leaf area, leaf area index, and vegetative growth index) and yield components (corm length, corm diameter, corm mass, yield, and total biomass). Planting density influenced the leaf area and the leaf area index ($P < 0.05$). The watering regime did not affect taro growth or yield components. Corm mass (0.59 kg), total biomass (49.8 t/ha), and yield (13.38 t/ha) were all the highest in the 30% FC. The 1 m × 0.5 m spacing produced the highest corm mass (0.62 kg). The high planting density (0.5 m × 0.5 m) resulted in the highest total biomass (70.2 t/ha), yield (20.84 t/ha), and harvest index (30.44%). As a result, the 0.5 m × 0.5 m planting density and 30% FC watering regime are recommended to farmers in the area for increased yields and food security.

1. Introduction

Taro (*Colocasia esculenta* (L.) Schott) is a herbaceous, monocotyledonous, perennial stem root crop widely grown in the world's tropical and subtropical areas [1]. Its production has more than doubled in the last decade, making it the fifth most consumed root vegetable in the world [2] and the oldest crop, having been utilized in Southeast Asia and India for over 9000 years [3]. It is one of the most underutilized crops in sub-Saharan Africa and an important staple food in the human diet. However, it ranks lower than other tubers such as sweet potato (*Ipomoea batatas*), potato (*Solanum tuberosum*), and cassava (*Manihot esculenta*) [4]. Taro yields on average in Africa remain low, with annual yield rarely exceeding one ton per hectare in East Africa [5] compared to Africa (5.9 tons/ha) and the world (6.6 tons/ha) [4].

It is one of the underutilized crops in Kenya, mainly cultivated by subsistence farmers and mostly women for its fleshy corms and nutritious leaves [6]. The crop acts as a buffer crop during the shortage of other staple foods. In Kenya, it is referred to as arrowroot or nduma and is primarily grown in the riverbeds. However, the riverbeds are already a limited resource in the face of climate change and especially during water scarcity periods. This has led to its production in semiarid areas and its large-scale cultivation being constrained by the lack of quality seeds and slow productivity [6–8]. The crop has the potential to address food insecurity and can be promoted to contribute to food diversity and improve livelihoods. However, little attention has been given to its production in Kenya. Understanding the growth response of taro under selected watering regimes and its water use under varied planting densities underpins this study.

Farmers in Kirinyaga, Embu, and Murang'a counties in Kenya have adopted moisture beds in the uplands for taro growing, a shift from growing in riverbeds and streams. A moisture bed is constructed by digging a trench and removing 0.3 metres of topsoil that is then mixed with manure. The dimensions of the bed vary in terms of width and length, with dimensions of up to 10 metres by 1.2 metres [9]. Polythene paper is laid on the floor of the bed, and its dimensions depend on those of the moisture bed. The polyethylene liner laid on the floor of the bed is then covered with soil mixed with manure to complete the moisture bed [9, 10]. The polythene sheet ensures water is retained in each plot and, hence, is available to the plants. The moisture beds make drip irrigation applicable within the plant rows [9]. Since taro plant spacing influences taro growth, corm shape, and yield because of competition for soil moisture, nutrients, and light [11], it is therefore imperative to know the implications on taro growth in terms of planting density under a moisture bed.

The use of drip irrigation for taro production provides an alternative to planting taro in the uplands as opposed to traditionally along rivers and streams and acts as a way for smallholder farmers to improve yields and increase harvests while considering the limited water resources available [12]. Moisture beds are lined with thick polyethylene sheets and trenched at a depth of 1 metre to separate the plots to prevent water seepage and lateral movement of water between plots [13]. Therefore, this study seeks to investigate taro growth, yield, and yield components under varying watering regimes and planting densities.

2. Materials and Methods

2.1. Study Site Description. The study was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO), Embu Research Centre. Embu County is located between latitudes 0° 8′ and 0° 50′ South and longitudes 37° 3′ and 37° 9′ East [14] (Figure 1). The Research Centre receives 1250 mm of annual rainfall in two rainy seasons, as shown in Figure 2, where March to May represents the long rainy season and October to December is the short rainy season, and the amount varies with altitude. The temperature ranges from 12°C in July to 30°C in March and September, with a mean temperature of 21°C. The soils are well-drained, very deep, have a strong structure, and are predominantly clay [15, 16]. The soil's physical and chemical properties analyzed are shown in Table 1. The composite soil samples were analyzed using standard methods as described in Okalebo et al. [17]. The total nitrogen is very low (0.09%), and the soil pH is slightly acidic (5.12) (Table 1), that is the preferred pH for the growth of taro [18].

2.2. Experimental Layout. A field experiment was established in March 2021 and ran for two cropping seasons during the long rains (LR) (March–August 2021) and short rains (SR) (September 2021–March 2022), i.e., LR 2021 and SR 2021/2022. A factorial experiment with a split-plot layout arranged in a completely randomized block design was used. The main factor was the irrigation levels, while the subfactor was the planting density, with three replications. The three irrigation levels were at 100%, 60%, and 30% based on the field capacity (FC). The planting densities used were 0.5 m × 0.5 m (40,000 plants ha^{-1}), 1 m × 0.5 m (20,000 plants ha^{-1}), and 1 m × 1 m (10,000 plants ha^{-1}), which are representative of high, medium, and low planting densities, respectively. Time in days after planting (DAP) and season were considered experimental factors to test the changes within and across the growing seasons.

2.3. Planting Material. Taro basal stems were sourced from farmers' fields in Kirinyaga County. The planting materials were collected from the apical 1-2 cm of the corm with the basal 15–20 cm of the petioles attached. The common landrace and commercially preferred and available variety was the Dasheen variety, which is characterized by one large cylindrical main corm and is preferred by the farmers in the region.

2.4. Irrigation and Moisture Bed Preparation. Drip irrigation was adopted for the study. The dripper line spacing was based on the plant spacing for each plot. Each plot was 4 m × 4 m, separated by 2 m wide spacing. Each plot was dug to a 50 cm depth and lined with a double-folded black polythene sheet to create a moisture bed. The polythene sheet prevented seepage and lateral water movement between plots. The dug-out soil from each plot was mixed with manure at a ratio of 2 : 1 and then returned to each plot (moisture bed) while leaving a depression of about 10 cm.

The soil moisture was maintained at field capacity (Table 1) for the first two months for good taro crop establishment. Thereafter, the watering regime treatments were applied. Irrigation was applied three times every week, during the mornings to ensure water availability during peak periods of demand in the day. The total actual amount of irrigation water applied ranged from 8000 litres (100% FC) to 4000 litres and 2000 litres for 60% and 30% FC, respectively. The soil water status during the growing period was monitored using a digital handheld moisture sensor meter (HSM50).

2.5. Growth and Yield Components' Measurements. Canopy characteristics (plant height, the number of leaves, leaf area, and leaf area index (LAI)) were determined once the plants reached 90% establishment. Five plants were tagged on each plot for data collection and monitored

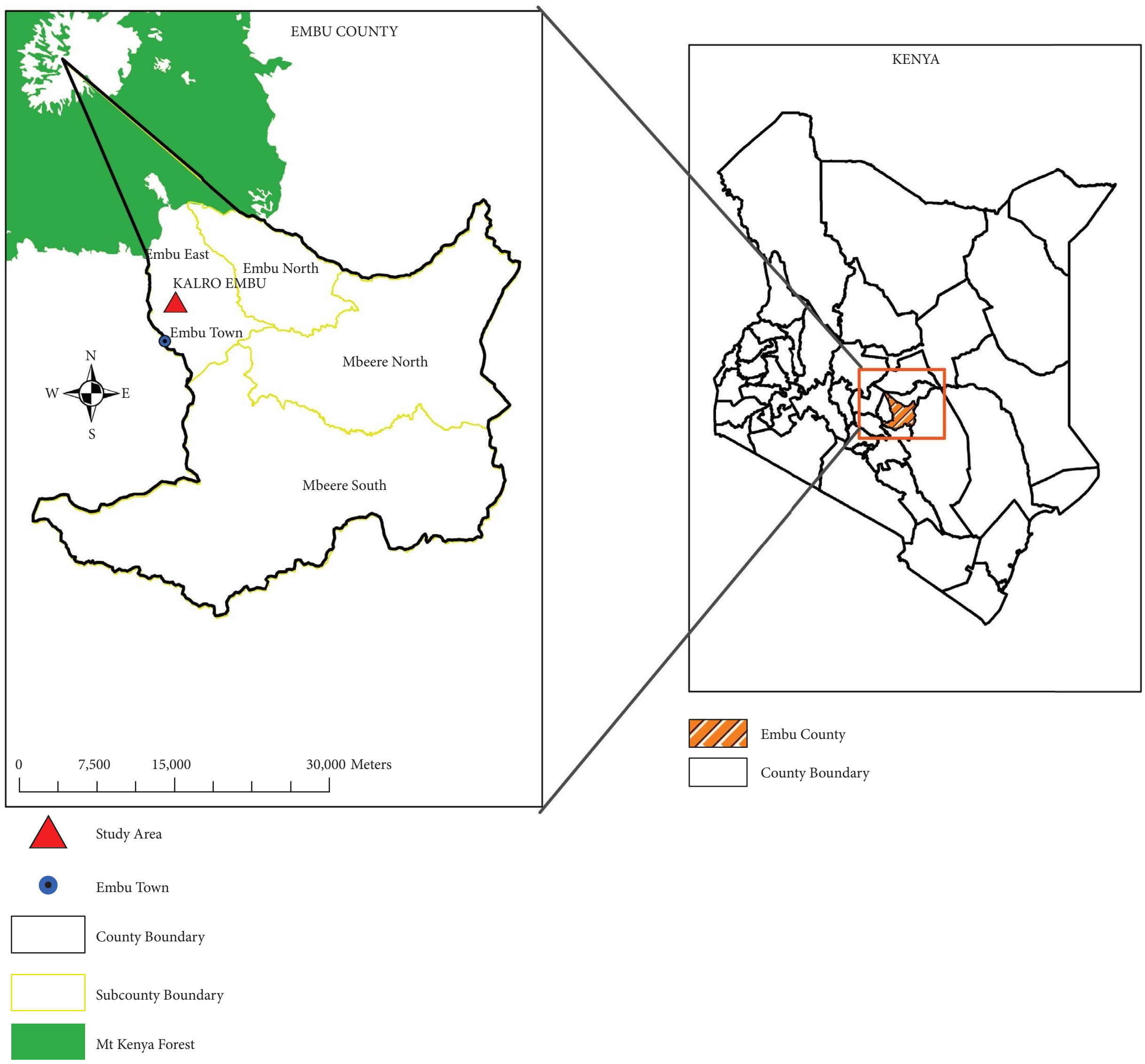

Figure 1: Location of the study site, KALRO, Embu, Kenya.

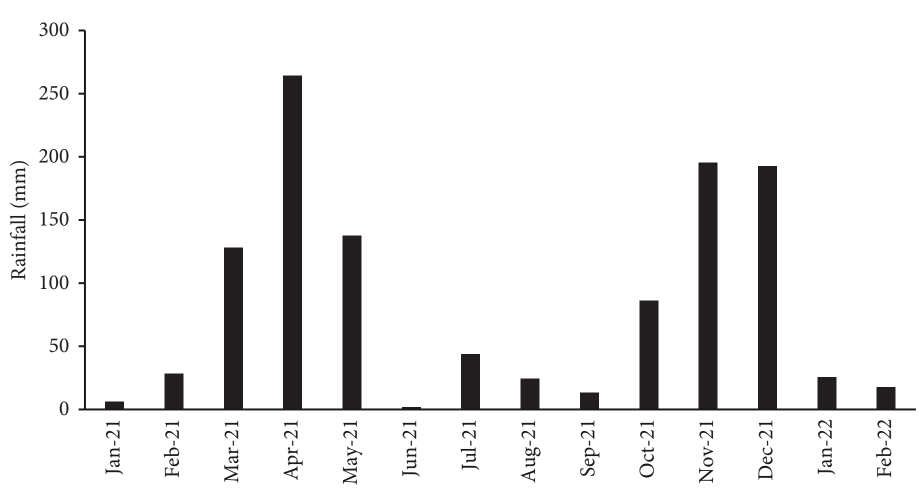

Figure 2: Monthly rainfall averages during the two growing seasons (LR 2021 and SR 2021/2022) of taro (*Colocasia esculenta*) at KALRO, Embu.

Table 1: Baseline soil physical and chemical properties of the experimental site (0–30 cm) at KALRO, Embu.

Soil property	Value
Chemical properties	
pH	5.12
Organic carbon (%)	2.10
Total nitrogen (%)	0.09
Potassium (mg kg^{-1})	624.0
Phosphorous (mg kg^{-1})	50.75
Sodium (mg kg^{-1})	26.45
Magnesium (mg kg^{-1})	154.8
Calcium (mg kg^{-1})	700.0
Iron (mg kg^{-1})	32.15
Manganese (mg kg^{-1})	143.50
Zinc (mg kg^{-1})	51.70
Physical properties	
Bulk density (g/cm^3)	1.06
Sand (%)	42.0
Silt (%)	16.0
Clay (%)	42.0
Textural class	Clay
Saturated hydraulic conductivity (ksat) (cm/hr)	13.36
Permanent wilting point (PWP) (% volume)	16.0
Field capacity (FC) (% volume)	37.8

throughout the growing seasons for growth and yield components. The plant height (cm) was measured from the ground up to the base of the plant's second-youngest fully unfolded leaf. Only fully unfolded leaves with at least 50% green leaf area were counted for leaf number. The number of standing leaves on each plant was also counted. The leaf area was determined by measuring the lengths and widths of the second-youngest fully unfolded leaf, and the LAI was determined by dividing the total leaf area of a taro plant by the total land area occupied by a single plant.

Yield and yield components (total biomass, total corm mass per plant, corm length, and corm diameter) were measured at harvest. Biomass was determined by weighing the shoots together with roots that are corms in taro, and corm mass was determined by weighing the corms only. The corm length is the distance from the tip of the corm to a point where the outer leaf petiole is attached to the corm. The diameter of the cross-section of the corm at the point where the outer leaf petiole is attached to the corm was taken as the corm diameter. The corm yield was calculated based on the mean experimental plot area and later adjusted to metric tonnes per hectare (tonnes/ha = Mg ha^{-1}). The harvest index is the proportion of corm yield [Y] to the total biomass [B] and was determined as follows:

$$\text{Harvest Index} = \frac{\text{Corm Yield}\,[Y]\,(t/ha)}{\text{Total Biomass}\,[B]\,(t/ha)}. \tag{1}$$

The vegetative growth index was also measured as described by Lebot [19] in Mabhaudhi and Modi [20].

$\text{VGI} = ((\text{Leaf width} \times \text{leaf length}) \times \text{leaf number}) \times H/100) - (\text{suckers} + \text{stolons})^2$, where VGI = vegetative growth index and H = plant height.

2.6. Statistical Analysis. Plant growth, yield, and yield components data collected were subjected to analysis of variance using the GenStat statistical software. The mean separation was done using the least significant difference (LSD) at a 5% level of probability where the ANOVA *F*-values were significant.

3. Results

3.1. Plant Growth and Yield Components as Influenced by Watering Regimes and Planting Density

3.1.1. Taro Height. The plant height increased with time and between the planting densities ($P = 0.008$) in the LR 2021 season (Figure 3). There was a steady increase in the plant height within the first few weeks up to 100 DAP; thereafter, the 1 m × 1 m density maintained the tallest plants. In the SR 2021/2022 season, the plant height increased up to 119 DAP, and thereafter decreased to 175 DAP ($P < 0.001$) (Figure 3). The watering regime did not influence the plant height in both seasons. Based on the two-season mean values on watering regimes, the 60% FC attained the tallest plants (63.84 cm), and the lowest in the 100% FC (60.49 cm).

3.1.2. Taro Leaf Area and Leaf Area Index (LAI). The leaf area increased progressively with time ($P < 0.001$) in both seasons (Table 2). In the LR 2021 season, a significant interaction between time and planting density ($P < 0.001$) was noted. The watering regime did not influence the leaf area in both seasons. Based on a two-season average, the 30% FC watering regime (909.4 cm^2) and 1 m × 1 m planting density (974.4 cm^2) attained the highest leaf area. The seasonal watering regime trend of 30% FC > 60% FC > 100% FC was observed. The mean values from the two seasons further showed a 1 m × 1 m > 1 m × 0.5 m > 0.5 m × 0.5 m trend in the leaf area under the different planting densities. The number of leaves was also determined throughout the planting seasons. The average number of leaves per plant was higher in the LR 2021 (5 leaves) than in the SR 2021/2022 season (4 leaves) and this was attributed to higher rainfall received in the LR 2021 season (Figure 2).

The significant differences between time ($P < 0.001$) and its interaction with planting density ($P < 0.001$) were noted for both seasons for the LAI (Table 2). A two-season average shows that the LAI was lowest during the 100% FC watering regime (0.18) and 1 m × 1 m planting density (0.10), and the highest under the 30% FC watering regime (0.21) and 0.5 m × 0.5 m planting density (0.31). Furthermore, the planting density average trend of 0.5 m × 0.5 m > 1 m × 0.5 m > 1 m × 1 m was noted for LAI.

3.2. Vegetative Growth Index (VGI). The vegetative growth index (VGI) was only determined for the second season (SR 2021/2022). In the first season (LR 2021), the suckers and stolons did not appear in the tagged plants, but in the other plants; hence, the VGI could not be determined. In the SR 2021/2022 season, the VGI increased with time within the different treatments ($P < 0.001$) (Table 2). The 60% FC

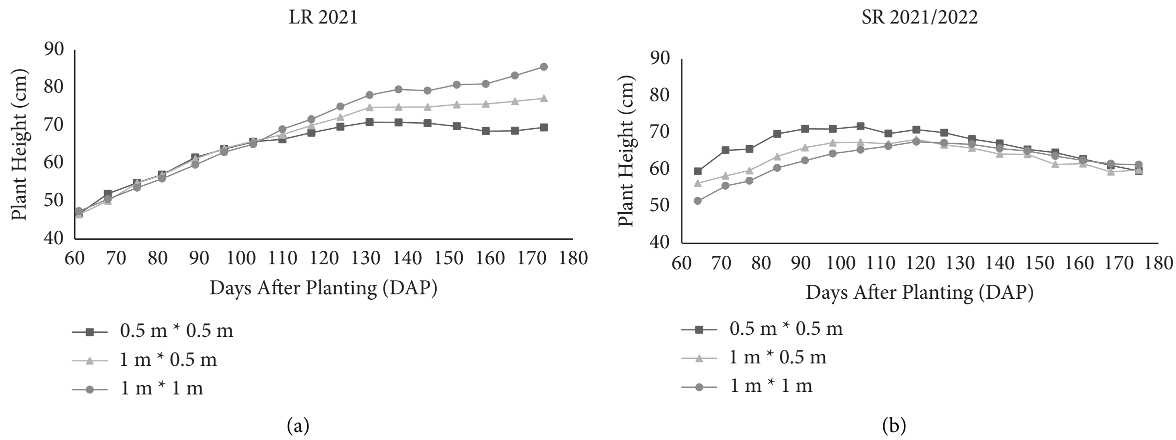

Figure 3: Taro (*Colocasia esculenta*) plant height as affected by planting densities in Embu, Kenya. (a) LR 2021. (b) SR 2021/2022.

Table 2: Taro leaf area, the leaf area index (LAI), and the vegetative growth index (VGI), as influenced by watering regime and planting density in Embu, Kenya.

	Long rains, 2021		Short rains, 2021/2022		
	Leaf area (cm^2)	LAI	Leaf area (cm^2)	LAI	VGI
Watering regime (WR)					
100% FC	890.6	0.18	819.6	0.18	2608
60% FC	884.5	0.19	922.6	0.19	3120
30% FC	957.2	0.20	861.5	0.22	2590
Planting density (PD)					
1 m × 1 m	1060.3	0.11	888.5	0.09	3041
1 m × 0.5 m	906	0.18	868	0.18	2716
0.5 m × 0.5 m	766.1	0.29	847.2	0.32	2559
Significant levels					
Time (DAP)	<0.001	<0.001	<0.001	<0.001	<0.001
WR	0.688	0.843	0.835	0.408	0.802
PD	0.019	<0.001	0.971	<0.001	0.863
WR ∗ PD	0.281	0.842	0.480	0.300	0.509
Time ∗ WR	0.713	0.903	0.953	0.736	0.919
Time ∗ PD	<0.001	<0.001	0.605	<0.001	0.433
Time ∗ WR ∗ PD	0.288	0.362	0.244	0.143	0.380

DAP = days after planting, FC = field capacity, LAI = leaf area index, PD = planting density, VGI = vegetative growth index, and WR = watering regime.

watering regime and 1 m × 1 m planting density had the highest VGI values of 3120 and 3041, respectively. The watering regime averages for VGI was 60% FC > 100% FC > 30% FC and under the different planting densities, a mean trend of 1 m × 1 m > 1 m × 0.5 m > 0.5 m × 0.5 m was observed.

3.3. Taro Corm Yield Components. The corm length, corm diameter, corm mass, yield, harvest index ($P < 0.001$), and total biomass ($P = 0.040$) were influenced by the seasons (Table 3). The short rains (SR 2021/2022) season showed lower values for the corm length, diameter, and total biomass. The watering regime did not influence any of the taro yield and yield components in the two seasons (Table 3). Planting density influenced the corm length ($P = 0.006$), corm diameter ($P = 0.004$), total biomass ($P < 0.001$), and corm yield ($P < 0.001$) but not the corm mass ($P = 0.346$) and the harvest index ($P = 0.306$) (Table 3).

The corm length showed a significant interaction between season and planting density ($P = 0.045$), with the LR 2021 season (12.57 cm) having a higher corm length than the SR 2021/2022 season (10.75 cm) (Table 3). The 1 m × 1 m planting density attained the highest corm length (12.15 cm) (Table 3) with a two-season average trend of 1 m × 1 m > 1 m × 0.5 m > 0.5 m × 0.5 m. A two-season average showed that the 1 m × 0.5 m planting density attained the highest corm mass (0.62 kg) and the lowest corm mass (0.52 kg) noted in the 0.5 m × 0.5 m planting density.

Total crop biomass was highest in the LR 2021 season (53.2 t/ha) than in the SR 2021/2022 season (42.6 t/ha) (Table 3). On average, the 0.5 m × 0.5 m planting density (40,000 plants ha^{-1}) had the highest biomass (70.2 t/ha) and the lowest in the 1 m × 1 m planting density (10,000 plants ha^{-1}) (27.0 t/ha) (Table 3). The corm yield was highest in the SR 2021/2022 (18.26 t/ha) than in the LR 2021 season (7.76 t/ha). A higher harvest index was obtained in the SR 2021/2022 (43.74%) than in the LR 2021 season (13.92%) (Table 3).

Table 3: Yield and yield components (corm length, corm diameter, corm mass, corm yield, total biomass, and harvest index) as affected by the watering regime and planting density in Embu, Kenya.

	Corm length (cm)	Corm diameter (cm)	Corm Mass (kg)	Total biomass (t/ha)	Corm yield (t/ha)	Harvest index (%)
Season						
LR 2021	12.57	10.20	0.37	53.2	7.76	13.92
SR 2021/2022	10.75	8.94	0.79	42.6	18.26	43.74
Watering regime						
100% FC	11.62	9.32	0.55	47.2	12.75	30.76
60% FC	11.73	9.72	0.58	46.7	12.95	28.20
30% FC	11.65	9.67	0.59	49.8	13.38	27.53
Planting density						
1 m * 1 m	12.15^{b}	10.12^{b}	0.59	27.0^{a}	5.81^{a}	26.81
1 m * 0.5 m	11.86^{b}	9.64^{b}	0.62	46.6^{b}	12.44^{b}	29.23
0.5 m * 0.5 m	10.98^{a}	8.95^{a}	0.52	70.2^{c}	20.84^{c}	30.44
Significant levels						
Season	<0.001	<0.001	<0.001	0.040	<0.001	<0.001
WR	0.992	0.842	0.928	0.942	0.970	0.616
PD	0.006	0.004	0.346	<0.001	<0.001	0.306
WR * PD	0.081	0.341	0.921	0.145	0.962	0.514
Season * WR	0.957	0.232	0.816	0.332	0.826	0.361
Season * PD	0.045	0.219	0.598	0.785	0.005	0.987
Season * WR * PD	0.256	0.499	0.664	0.226	0.668	0.857

FC = field capacity, PD = planting density, WR = watering regime, and different letters within columns indicate significant differences at a 5% probability level.

The closely spaced plants (0.5 m × 0.5 m) had the highest harvest index (30.44%) and the lowest (26.8%) with the widely spaced plants (1 m × 1 m). A watering regime trend of 100% FC > 60% FC > 30% FC was noted, that suggest that high moisture availability positively influences the harvest index.

The correlation analysis of the yield components is represented in Table 4. The results shows that the corm yield had negative and nonsignificant correlations with corm length ($r = -0.0592$) and corm diameter ($r = -0.0744$). The total biomass ($r = 0.6037$), and harvest index ($r = 0.5472$) had positive correlations with the yield while the corm mass ($r = 0.6484$) had the strongest positive correlation with the yield, showing its strong influence on the determination of the corm yield.

Table 4: Correlation matrix of taro yield components (corm length, corm diameter, corm mass, total biomass, corm yield, and harvest index) based on LR 2021 and SR 2021/2022 seasonal averages.

	CL	CD	CM	TB	CY	HI
CL	—					
CD	0.8126^{**}	—				
CM	0.1124	0.2095	—			
TB	0.3108^{*}	0.338^{*}	0.1395	—		
CY	−0.0592	−0.0744	0.6484^{**}	0.6037^{**}	—	
HI	-0.5089^{**}	-0.521^{**}	0.6157^{**}	−0.1899	0.5472^{**}	—

Where CL = corm length, CD = corm diameter, CM = corm mass, TB = total biomass, CY = corm yield, HI = harvest index. $^{*} = P < 0.05$, $^{**} = P < 0.001$.

4. Discussion

4.1. Taro Height. The lower plant height observed under 100% FC, and 30% FC showed excess water and limited water conditions did not favour taro plant height. Clay soils in the study area are subject to compaction during moist and wet conditions and crusting when dry impeding infiltration and reducing water availability to the root zone [21]. Lower plant height under limited water conditions was also observed by Mabhaudhi [13], and Li et al. [22] in South Africa and Brazil, respectively, working on sandy clay loam soil.

Planting density did not have a significant effect on the plant height, and this could be attributed to the fact that taro grows laterally by producing more shoots. The reduced plant height in higher planting densities may be attributed to competition for light, moisture, and nutrients and as a consequence of lower photosynthesis [23, 24]. The lowest planting density (1 m × 1 m) had the tallest plants, similar to the results observed by Sibiya [25], in South Africa. Contrary, Boampong et al. [11] in Ghana working on well-drained silty loam soils, found that taro spaced at a higher spacing of 1 m × 1 m attained lower plant height at the peak of vegetative growth. Alemu et al. [26] in Ethiopia, found that taro height increased as planting density increased, and attributed this to an increase in linear growth due to higher plant density per unit area.

4.2. Taro Leaf Area (LA) and Leaf Area Index (LAI). Limited water availability (30% FC) favoured LA and LAI, while excess water availability (100% FC) lowered these parameters. The high LA and LAI values under the 30% FC watering regime could be attributed to the fact that clay soils have smaller pores and higher water retention under lower water availability. These findings contradict those by Mabhaudhi et al. [27] in South Africa, who found a reduction in the leaf area index at 30% and 60% ETc compared with that of 100% ETc while working with Dasheen and Eddoe taro varieties, on sandy clay loam soil. The reduction of the leaf area and the leaf area index is due to the reduction of photosynthesis under water constraints that leads to reduced leaf expansion [24, 28]. In a study by Mabhaudhi [13]; water stress reduced the leaf area and plant height of taro varieties and attributed the reduced leaf area to premature senescence of old leaves. As a result, a decrease in canopy characteristics may indicate water stress and assist farmers in determining that irrigation is required.

The low planting density had the highest leaf area, while the lowest leaf area was recorded in the high plant density due to the limited moisture and light availability for each plant as a result of competition. The findings were similar to Alemu et al. [26] who found that leaf area per plant increased with decreasing planting density. The highest LAI recorded from the high planting density can be attributed to the high leaf number contribution from many plants per unit area. Maximum LAI has also been observed in high plant density in Ethiopia [29] and in wetland-grown taro plant populations in Uganda [30].

4.3. Vegetative Growth Index (VGI). The VGI was lower under the 30% FC, and this further relates to the low plant height and leaf area observed for the SR 2021/2022 season, where the VGI was recorded. The reduction in VGI is attributed to low and lack of sucker and stolon formation throughout the growing season. The plant height, leaf area, suckers and stolons, and water availability highly affected the VGI, and high values of VGI were observed where these parameters were the highest. The lowest planting density had the highest VGI, while the highest density had the lowest, and this can be attributed to the fact that the number of suckers per plant increases as the plant spacing increases. The increase in the number of suckers with lower planting densities may be due to the availability of more nutrients, moisture, and low competition for light [11]. Low VGI was also observed in limited water conditions by Mabhaudhi [13] in South Africa. Soulard et al. [31], in Vanuatu, found similar results where tall taro plants produced more and bigger leaves, more suckers, and hence higher VGI values.

4.4. Taro Corm Yield Components. The different cropping seasons significantly influenced the yield components with the corm length, diameter, and total biomass values being higher in the LR 2021 season than in the SR 2021/2022 season. This can be attributed to the higher average rainfall received in the long rains (LR) 2021 season (99.9 mm) than the short rains (SR) 2021/2022 (88.3 mm) (Figure 2). The 100% FC produced the lowest corm diameter, signifying that high water availability affected corm diameter by reducing its size. The 30% FC watering regime attained the highest corm mass and yield, supporting the notion that low moisture availability favoured corm formation, to that Shelembe [32]; contradictory results were found in South Africa.

The high harvest index in the SR 2021/2022 was lower than in the LR 2021 season was due to the lower biomass and higher yield obtained in the latter. This implies more corm growth as opposed to vegetative growth in the season. A positive effect on moisture stress was noted in the high moisture availability (100% FC), where the harvest index was highest, and this proves the ability of taro to convert biomass to economic yield more efficiently in water-logged conditions than under limited water conditions. These findings contradict those by Mabhaudhi [13], working with Dasheen and Eddoe varieties. Taro plants with a high harvest index had the highest corm yield similar to studies by Lu et al. [33] and Shelembe [32], in Taiwan and South Africa, respectively.

The low values of corm length, diameter, and mass under the highest planting density were attributed to competition for light, moisture, and nutrients at closer spacing similar to results by Sibiya [25], working in South Africa. As the plant density increases, there is a decrease in plant performance due to competition and lower photosynthetic rates [34], as evidenced by a reduction in canopy characteristics (plant height and leaf area), as well as corm length, diameter, and mass. The highest total biomass and corm yield per hectare attained from the high planting density can be attributed to more plants per unit area at lower plant spacing. The large number of plants per area intercepts solar radiation while ensuring sufficient ground cover [11, 30, 35].

It is further notable that the yields observed from the different watering regimes and planting densities in this study were greater than the East African, African, and world averages of ≤1 t/ha, 5.6 t/ha, and 6.6 t/ha, respectively [4, 5]. The total yield in taro is a function of the number of corms produced per unit area rather than the size of the individual corm/corm mass. This means that more corms are produced from high planting densities, and hence, higher yields because of the large number of taro plants per unit area.

The correlation analysis showed that the corm yield had a positive and significant correlation with corm mass, total biomass, and harvest index but a negative correlation with corm diameter and length. This means higher yields were associated with low corm length and diameter and higher values of corm mass, total biomass, and harvest index. Eze and Nwofia [36], in Nigeria, reported that corm mass had a positive effect on taro yield, implying that larger corm sizes resulted in higher yields. Boampong et al. [11] in Ghana, on the other hand, found that corm yield had a positive correlation with corm length and diameter. Positive and significant effects of the corm mass, total biomass, and harvest index show their importance in the determination of yield and indicate that an increase in these components will increase the taro yields.

5. Conclusion

Planting density significantly affected the taro height, leaf area, and leaf area index. The watering regime did not have a significant effect on growth parameters (plant height, leaf area, leaf area index, and the vegetative growth index) and yield components across the two seasons. The long rains season received higher rainfall and favoured higher values of corm length, corm diameter, and total biomass but lower values for corm mass, corm yield, and harvest index. Limited water conditions (30% FC) produced the highest total biomass, corm mass, and corm yield. The highest density, $0.5\,\mathrm{m} \times 0.5\,\mathrm{m}$ (40,000 plants ha^{-1}), produced the highest total biomass and corm yield per hectare. Therefore, the $0.5\,\mathrm{m} \times 0.5\,\mathrm{m}$ planting density and a 30% FC watering regime are recommended to farmers in the area for reduced water costs, increased yields, and food security.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors greatly acknowledge the International Foundation for Science for funding the study through grant no. C-6530-1. The authors sincerely thank the KALRO Embu for their research farm and Mary Nyaguthii for the technical support in the field.

References

[1] Food and Agriculture Organization of the United Nations (Fao), *Chapter 5: Soil Crusting and Sealing*, Natural Resources Management and Environment Department vol. 69, 2015, http://www.fao.org/docrep/t1696e/t1696e06.htm.

[2] W. M. Mercy, M. R. Steven, N. M. Alice, and P. Valerie, "Genetic structure and diversity of East African taro [Colocasia esculenta (L.) Schott]," *African Journal of Biotechnology*, vol. 13, no. 29, pp. 2950–2955, 2014.

[3] V. R. Rao, P. J. Matthews, P. B. Eyzaguirre, and D. Hunter, "The global diversity of taro ethnobotany and conservation," in *Museum*Bioversity International Rome, Italy, 2010, https://www.bioversityinternational.org/fileadmin/_migrated/uploads/tx_news/The_global_diversity_of_taro__ethnobotany_and_con servation_1402.pdf.

[4] V. A. Palapala and P. E. Akwee, "Genetic diversity analysis of Kenyan taro [Colocasia esculenta (L.) Schott] accessions using SSR markers," *Sky Journal of Agricultural Research*, Vol. 5, issue no. 5, 2016, http://erepo.usiu.ac.ke:8080/xmlui/handle/11732/4495.

[5] A. K. Serem, V. A. Palapala, H. Talwana, J. O. M. Nandi, B. Ndabikunze, and M. K. Korir, "Socioeconomic constraints to sustainable cocoyam production in the lake victoria crescent," *African Journal of Environmental Science and Technology*, Vol. 2, issue no. 10, 2008, http://erepo.usiu.ac.ke:8080/xmlui/handle/11732/4504.

[6] A. Ngetich, S. Runo, O. Ombori et al., "Low cost micropropagation of local varieties of taro (Colocasia esculenta spp.)," *British Biotechnology Journal*, vol. 6, no. 4, pp. 136–145, 2015.

[7] P. E. Akwee, G. Netondo, J. A. Kataka, and V. A. Palapala, "A critical review of the role of taro Colocasia esculenta L. (Schott) to food security: a comparative analysis of Kenya and Pacific Island taro germplasm," *Scientia Agriculturae*, vol. 9, no. 2, pp. 101–108, 2015.

[8] P. W. Wambugu and Z. K. Muthamia, "The state of plant genetic resources for food and agriculture in Kenya," 2009, http://www.fao.org/pgrfa-gpa-archive/ken/kenya2.pdf.

[9] J. Boland, *Urban Agriculture*, 2 edition Wageningen, The Netherlands, 2005, https://cgspace.cgiar.org/bitstream/handle/10568/73089/urban_agriculture.pdf?sequence=1.

[10] D. Muchui, *Forget Swamps, Our Arrowroots Grow on Simple Moisture Beds | Kenya*, The Nation Newspaper Nairobi, Kenya, 2015.

[11] R. Boampong, S. K. Boateng, R. Adu Amoah, B. Adu Gyamfi, L. M. Aboagye, and E. O. Ansah, "Growth and yield of taro (Colocasia esculenta (L) Schott.) as affected by planting distance," *International Journal of Agronomy*, Article ID 8863099, 2020.

[12] G. K. Wainaina, "Challenges in adoption of water-saving practices: perspective from drip irrigation adoption in Kenya," *World Water Policy*, vol. 7, no. 1, pp. 74–87, 2021.

[13] T. Mabhaudhi, "Drought Tolerance and Water-Use of Selected South African Landraces of Taro (Colocasia Esculenta L. Schott) and Bambara Groundnut (Vigna Subterranea L. Verdc) [PhD," http://hdl.handle.net/10413/10027 Thesis, University of Kwazulu-Natal, Durban, South Africa, 2012, http://hdl.handle.net/10413/10027 Thesis.

[14] K. Ruth, W. C. Everlyn, K. James, W. Boaz, and N. Innocent, "Determinants of climate change adaptation and perceptions among small-scale farmers of Embu County, Eastern Kenya," *African Journal of Environmental Science and Technology*, vol. 15, no. 4, pp. 167–178, 2021.

[15] M. O. Kisaka, M. Mucheru-Muna, F. K. Ngetich, J. N. Mugwe, D. Mugendi, and F. Mairura, "Rainfall variability, drought characterization, and efficacy of rainfall data reconstruction: case of eastern Kenya," *Advances in Meteorology*, Vol. 2015, Article ID. 380404, 2015.

[16] Embu County Government, *Embu County Government County Integrated Development Plan 2018-2022 A Vibrant and Prosperous County*, Embu, Kenya, 2019, https://www.embu.go.ke/wp-content/uploads/2019/09/APPROVED-CIDP-2018-2022.pdf.

[17] J. R. Okalebo, K. W. Gathua, and P. L. Woomer, *Laboratory methods of soil and plant analysis: a working manual*, Sacred African Publishers, Zimbabwe, Africa, 2002, https://www.researchgate.net/publication/313605698_Laboratory_Methods_of_Soil_and_Plant_Analysis_A_Working_Manual, 2 edition.

[18] I. Onwueme, *Taro Cultivation in Asia and the Pacific Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific*, Bangkok, Thailand, 1999, http://ebooks.lib.ntu.edu.tw/1_file/FAO/67652/ac450e00.pdf.

[19] V. Lebot, *Tropical Root and Tuber Crops: Cassava, Sweet Potato, Yams and Aroids*, CABI, Cambridge, UK, 2008.

[20] T. Mabhaudhi and A. T. Modi, "Drought tolerance of selected South African Taro (Colocasia esculenta L. Schott) landraces," *Experimental Agriculture*, vol. 51, no. 3, pp. 451–466, 2015.

[21] Food and Agriculture Organization of the United Nations (Fao), "Pacific food security toolkit: building resilience to climate change root crop and fishery production," 2010, http://www.fao.org/3/am014e/am014e.pdf.

[22] M. Li, A. Cristina Fernandes Deus, and L. Chau Ming, "Response of taro to varying water regimes and soil textures," *Journal of Irrigation and Drainage Engineering*, vol. 145, no. 3, Article ID 04019001, 2019.

[23] M. K. Souri and M. Hatamian, "Aminochelates in plant nutrition: a review," *Journal of Plant Nutrition*, vol. 42, no. 1, pp. 67–78, 2019.

[24] M. Ebrahimi, M. K. Souri, A. Mousavi, and N. Sahebani, "Biochar and vermicompost improve growth and

physiological traits of eggplant (Solanum melongena L.) under deficit irrigation," *Chemical and Biological Technologies in Agriculture*, vol. 8, no. 1, p. 19, 2021.
[25] S. G. Sibiya, *Planting Density Effect on Growth and Yield of Taro (Colocasia Esculenta) Landraces*, https://researchspace.ukzn.ac.za/handle/10413/13427 MSc. Thesis, University of KwaZulu-Natal, KwaZulu-Natal, Southaffrica, 2015, https://researchspace.ukzn.ac.za/handle/10413/13427 MSc. Thesis.
[26] D. Alemu, T. Bizuayehu, W. Walelign, G. Amsalu, and A. K. Hvoslef-Eide, "Response of taro (Colocasia esculenta (L.)) to variation in planting density and planting dates on growth, radiation interception, corm and cormels yield in Southern Ethiopia," *African Journal of Agricultural Research*, vol. 13, no. 23, pp. 1186–1197, 2018.
[27] T. Mabhaudhi, A. T. Modi, and Y. G. Beletse, "Response of taro (Colocasia esculenta L. Schott) landraces to varying water regimes under a rainshelter," *Agricultural Water Management*, vol. 121, pp. 102–112, 2013.
[28] S. A. Anjum, X. Xie, L. Wang, M. F. Saleem, C. Man, and W. Lei, "Morphological, physiological and biochemical responses of plants to drought stress," *African Journal of Agricultural Research*, vol. 6, no. 9, pp. 2026–2032, 2011.
[29] M. Tsedalu, B. Tesfaye, and Y. Goa, "Effect of type of planting material and population density on corm yield and yield components of taro (Colocasia esculenta L.)," *Journal of Biology, Agriculture and Healthcare*, vol. 4, no. 17, 2014.
[30] R. Tumuhimbise, H. L. Talwana, D. Osiru et al., "Growth and development of wetland-grown taro under different plant populations and seedbed types in Uganda," *African Crop Science Journal*, vol. 17, no. 1, pp. 49–60, 2010.
[31] L. Soulard, P. Letourmy, T. V. Cao, F. Lawac, H. Chaïr, and V. Lebot, "Evaluation of vegetative growth, yield and quality related traits in taro (Colocasia esculenta [L.] Schott)," *Crop Science*, vol. 56, no. 3, pp. 976–989, 2016.
[32] S. C. Shelembe, "Water Use and Nutritional Water Productivity of Taro (Colocasia Esculenta L. Schott) Landraces," https://researchspace.ukzn.ac.za/xmlui/handle/10413/19572 MSc. Thesis, University of KwaZulu-Natal, KwaZulu-Natal, South Affrica, 2020, https://researchspace.ukzn.ac.za/xmlui/handle/10413/19572 MSc. Thesis.
[33] H. Y. Lu, C. T. Lu, L. F. Chan, and M. L. Wei, "Seasonal variation in linear increase of taro harvest index explained by growing degree days," *Agronomy Journal*, vol. 93, no. 5, pp. 1136–1141, 2001.
[34] S. Trimble, "Measuring competition in crop plants: mechanisms and outcomes," *CID Bio-Science*, 2021,https://cid-inc.com/blog/measuring-competition-in-crop-plants-mechanisms-outcomes/.
[35] J. J. C. Scheffer, J. A. Douglas, and C. M. Triggs, "Factors affecting the production and quality of Japanese taro cormels," *Acta Horticulturae*, vol. 670, pp. 167–172, 2005.
[36] C. Eze and G. Nwofia, "Variability and inter-relationships between yield and associated traits in taro (Colocasia esculenta (L.) Schott)," *Journal of Experimental Agriculture International*, vol. 14, no. 2, pp. 1–13, 2016.