Vol. 13(23), pp. 1186-1197, 7 June, 2018
DOI: 10.5897/AJAR2018.13141
Article Number: 649AB4757312
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Response of taro (*Colocasia esculenyta* (L.)) to variation in planting density and planting dates on growth, radiation interception, corm and cormels yield in Southern Ethiopia

Alemu Dessa[1*], Bizuayehu Tessfaye[2], Walelign Worku[2], Amsalu Gobena[2] and Anne Kathrine Hvoslef-Eide[3]

[1]College of Agriculture and Natural Resource, Dilla University P. O. Box 419, Dilla, Ethiopia.
[2]College of Agriculture, Hawassa Universities, P. O. Box 05, Hawassa, Ethiopia.
[3]Department of Plant Science, Faculty of Biosciences, Norwegian University of Life Sciences (NMBU), P. O. Box 5003, 1432 As, Norway.

Received 23 March, 2018; Accepted 7 May, 2018

Taro production is mainly affected by agroecology, planting time and planting density. To this effect, a field study was conducted to determine influences of planting density and planting dates on growth, radiation interception and yields of taro (*Colocasia esculenyta* (L.)). The experiment was conducted using four levels of planting density (15037, 19607, 26666 and 38461 plants ha^{-1}) and four planting dates from mid-February to mid-April at 21 days interval at Areka and Hawassa locations. SAS statistical software package was used for the analysis of the data derived from the experiment. From the analysis, interaction of location by planting dates significantly (p<0.01) influenced date of emergence, stand count and plant height. While, leaf area, leaf area index (LAI) and plant height, were significantly influenced due to location by planting density interactions. However, dry matter production (DMP) was influenced by planting density only. Cumulative interception photosynthetically active radiation (CIPAR), corm weight, cormels number, marketable yield and total yield per plant were significantly (p≤0.05) influenced both by plant density and planting dates. Maximum total and marketable yield were obtained from 15037 plant ha^{-1} at late and early March planting dates. Plant density and planting dates are therefore important agronomic management practices to improve the productivity of taro through enhancing the capacity of plant for light interception, growth and dry matter production.

Key words: Corm, cormels, dry matter, radiation interception, leaf area index (LAI).

INTRODUCTION

In Ethiopia taro (*Colocasia esculenta* (L)) is among the list of major root and tuber food crops that are consumed across the country. The crop is produced on about 52,201 ha of land with 40,600 ton per annum production (CSA, 2011). Since many tropical areas often experience unfavorable environmental conditions, the crop is

*Corresponding author. E-mail: kenanidessa@yahoo.com.

particularly important for food security to fill seasonal food gaps when other crops are not in the field (Beyene, 2013). In Ethiopia, Taro has extensively been cultivated in dense populated and high rainfall areas of South, Southwest and Western parts of the country (Dagne et al., 2014). Currently, taro production areas are increasing in Ethiopia due to the fact that the level of dependence on sweet potato and enset crop is shifting to maize and taro (Dagne et al., 2014; Tsedalu et al., 2014). Taro crop have multi-fold nutritional advantages; its corms are high in carbohydrate in the form of starch and low in fat and protein (John, 2007). It contains about 7% protein on a dry weight basis. This is more than yam, cassava or sweet potato (FAO, 1999). Its leaf also rich in protein, containing about 23% proteins on a dry weight basis. It is also a rich source of calcium, phosphorus, iron, Vitamin C, thiamine, riboflavin and niacin, which are important constituents of human diet (FAO, 1999; Onwueme, 1999; Ndon et al., 2003). Despite all this nutritional advantages, the current taro production in Ethiopia is very low (7.6 t/ha), compared to other countries like Egypt (31.1 t/ha), Mauritius (11.6 t/ha) (Manner and Taylor, 2011) and Malesia (50 t/ha in low land and 25 t/ha in dry land) (De la Pena and Plucknett, 1972). This indicates the need of further work to improve the situation.

In Ethiopia, farmers undertake taro planting at different times. Some farmers undertake planting at onset of rain (late March to early April); some plant during off season using residual moisture (November to December); some plant in dry season (January to February). But, planting is not common during main rainy season (May to September) (Personal communication with taro Breeder at Areka Agricultural Research Center). In general, there is no scientific recommendation of taro planting time in Ethiopia. On the other hand, the current climate change is another scenario that makes the rainy season unpredictable and shifting of seasons from year to year due to the latitudinal position of the country (Paul and Balaji, 2007).

The impact of climate change does not end in seasonal shifting but also affect both the macro and micro climatic environments. Thus, synchronization of planting dates with current situation may be a vital approach to cope up with the challenge. Concurrently, reports by Mare (2009) revealed that delayed planting negatively affected cormels number per plant and fresh cormels mass. In addition, Mare and Modi (2012) reported that delay in planting significantly decreased starch content on certain cultivars of taro.

On the other hand, radiation is one of the important basic meteorological parameters for crop production. Under favorable conditions, radiation plays a decisive role in vegetative growth and development. Excessive or insufficient exposure of taro crop to radiation was reported to reduce taro productivity (Bernardes et al., 2011). Interception of radiations on leaf surface cannot be controlled but can be manipulated for their maximum use by crop management means. Crop growth can be analyzed in terms of its efficiency to use intercepted radiations and the method has been used in various field crops (Hussain et al., 1998, 1999, 2002; Bernardes et al., 2011).

The fraction of radiation intercepted by crops increases hyperbolically with LAI; in many crops 80-85% of the incident radiation is intercepted when LAI is between 3.0 and 4.0, and 95% when LAI reaches 5.0 (Scott and Jaggard, 1978; Hussain et al., 2002). This shows that establishment of adequate plant canopy has important role on radiation interception and crop biomass production. Thus, the chosen crop spacing is based on the hypothesis that there is optimal plant population density that allows interception of ≥95% of the available photosynthetically active radiation (PAR) to give highest possible yield at specific growth period (Hussain et al., 2002). Purcell et al. (2002) reported that no additional yield advancement with further increase of plant population density can occur because of decrease in radiation use efficiency at higher plant population density. In addition, Maddonni et al. (2001) observed that light interception varied in different row distance and that changes leaf area index. Similarly, planting date has also relation with light interception. Uzun (1996) reported that when planting is commenced earlier than the actual time, plants are exposed to light radiation with a certain leaf area before adverse climate conditions. This is important particularly with respect to light and daily temperature unit accumulated during the growth period. There is also a case in which plant density depends on planting dates. According to Gendua et al. (2001), farmers may consider planting with a wider spacing during cooler months and with a narrower spacing during hotter months to optimize corm size and production. Similarly, reports by Abd-Ellatif et al. (2010) indicated that planting date and intra-row spacing interaction has a significant effect on vegetative growth parameters and total yield in which, early planting dates with closer distances between plants give the highest values for these characters.

In Ethiopia, so far, research on taro is mainly focused on breeding aspects such as germplasm collection, characterization, and selection activities while information on agronomic management such as plant density and planting date is very limited. Thus, information derived from this study expected to supports farmers' decision on planting date and planting density and gives researchers preliminary information for further taro plant eco-physiology studies in tropical environment. Therefore, the current study was initiated with the following objectives:

1. To evaluate the effect of planting density and planting dates on taro growth and canopy light interception
2. To investigate the effect of planting density and planting dates on taro corm and cormels yield and yield

Table 1. Soil physicochemical characteristics of the experimental site.

Location	Physicochemical characteristics							
	pH	Sand (%)	Silt (%)	Clay (%)	Texture	OC (%)	P (ppm)	TN (%)
Areka	5.3	16.9	33	50	Clay	2.3	6.6	0.15
Hawassa	7.6	40.9	29	30	Clay loam	2.8	17.7	0.08

OC: Organic matter content; P: Phosphourus; TN: Total nitrogen.

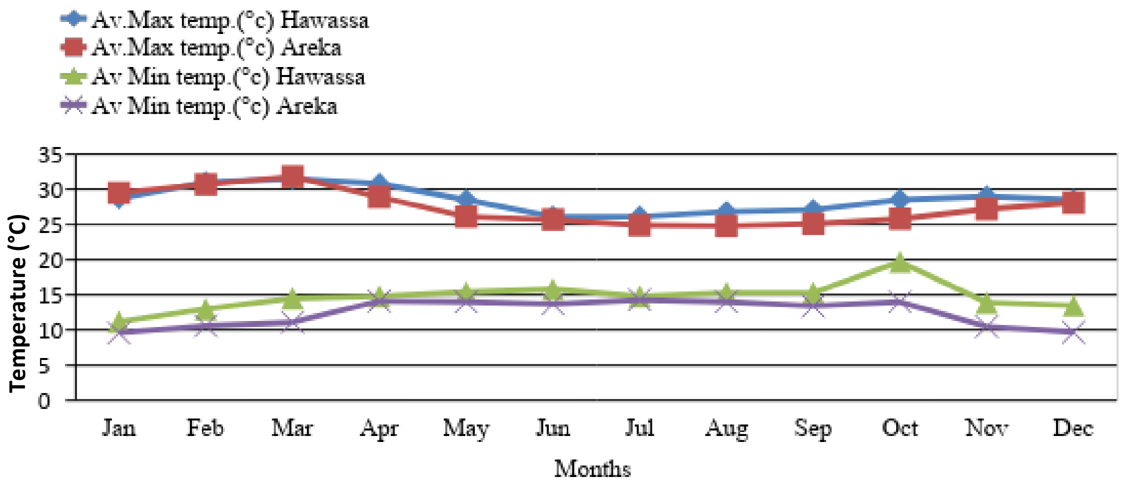

Figure 1A. Mean maximum and minimum temperature of the experimental site during the experimental period.

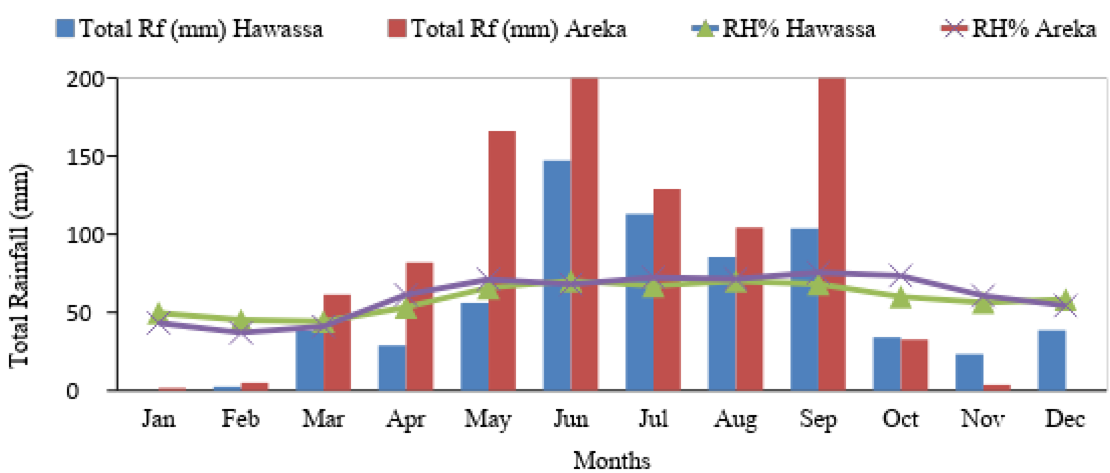

Figure 1B. Total rainfall and RH of the study area during the experimental year.

components

MATERIALS AND METHODS

Experimental sites

The experiment was conducted at Hawassa University (7°03' N latitude and 38°30'E longitude) and Areka Agricultural Research Center (7°06' N latitude and 38°37' E longitude), Southern Ethiopia, from February to December, 2015. Hawassa is located at 1700 m while Areka is located at 1800 m above sea level.

The physicochemical characteristics of the soil of the experimental sits presented in Table 1 are almost similar with the type of soil that suit taro production (Manner and Taylor, 2011).

The average maximum and minimum temperatures during the experimental period were 28.6 and 14.8°C at Hawassa and 26 and 15°C at Areka, respectively (Figure 1A). The total rainfall and relative humidity during the experimental period was also presented in Figure 1B.

Table 2. ANOVA table for date of emergency, stand count, plant height, shoot number, leaf number leaf area, LAI and CIPAR as affected by location, planting density and planting dates.

Sores of variation	Mean sum of square							
	Date of emergency	Stand count (%)	Plant height (cm)	Shoot number	Leaf number	Leaf area	LAI	CIPAR
Location (L)	368.2**	13608.84***	6581.11***	91.83***	3513.11**	4.47*	16.61^{ns}	-
Replication (Rep)	32.4^{ns}	1008.75**	1156.800***	8.43^{ns}	156.58^{ns}	5.02**	24.45*	489301***
Planting density (PP)	34.7^{ns}	47.59^{ns}	762.92***	21.17**	516.99**	5.68**	59.69***	125216**
Planting date (PD)	4282.1***	1907.70***	1039.37***	7.78**	120.99^{ns}	3.46*	15.31^{ns}	79040*
L*PP	65.1^{ns}	137.82^{ns}	454.52**	2.00^{ns}	62.76*	1.68^{ns}	35.68***	-
L*PD	316.5**	1097.34*	569.05***	0.57^{ns}	31.48^{ns}	0.66^{ns}	4.18^{ns}	-
PP*PD	66.6^{ns}	183.43^{ns}	129.69^{ns}	2.45^{ns}	45.32^{ns}	1.08^{ns}	7.72^{ns}	29356
L*PP*PD	69.2^{ns}	212.17^{ns}	105.94^{ns}	2.04^{ns}	45.38^{ns}	0.88^{ns}	7.28^{ns}	-

*, **and *** where significant at $P<0.05$, $P<0.01$ and $P<0.001$, respectively.

Treatments and experimental design

Four levels of planting density (15037, 19607, 26666 and 38461 plant ha^{-1}) and planting dates consisting February 14 (Mid-February), March 5 (Early March), March 26 (Late March), and April 16 (Mid-April) at 21 days interval were used as treatments at two locations (Areka and Hawassa). The experiment was conducted in RCBD factorial arrangement using three replications. Uniform corm size (250-300 g) of improved taro cultivar (Boloso-1) was used as a planting material.

Agronomic practices

The lands for the experiment were prepared in January and the first planting was made on 13th and 16th February 2015 at Areka and Hawassa respectively and the other three successive plantings were done at 21 days interval at each location. Equal does of P and N at 200 kg ha^{-1} were applied in the form of Triple Super Phosphate (TSP) and urea (CH_4N_2O). The nitrogen fertilizer was applied in spilt application at planting and 50 days after planting (Tadesse and Tesfaye, 2010). All agronomic managements were made manually as required during the growing period.

Data collection

Random sample of five plants from the three inner rows of each experimental plot were considered to determine plant height, shoot number per plant, number of leaf per plant, leaf area and leaf area index. To determine corm/cormels yield and other yield parameters, only three central rows were harvested and yield parameters such as number, length, diameter and weight of corm and cormels, marketable and total yield were recorded. Marketable yield was determined based on size and physical quality (Marketable = corm/cormels free from mechanical and pest injury, undeformed shape and acceptable size (>100 g)). All the vegetative growth data were collected during maximum physiological growth stage from 145 to 150 days after planting while the yield data were collected after all the vegetative growth are completed and the above ground biomass withered.

The radiation interception was evaluated for Hawassa site only. The data for cumulative Intercepted Photosynthetic Active Radiation (CIPAR) was determined from the incoming global radiation and ground cover data collected at ten days interval throughout growing period. Accordingly, the fraction of incoming Photosynthetic Active Radiation (PAR) intercepted by the canopy was recorded by measuring the ground cover at ten days interval using grids of 40×65, 50×75, 60×85 and 70×95 cm divided into 100 equal rectangles for planting densities of 38461, 26667, 19607 and 15037 plants per hectare, respectively. At every ten days, the grids were put between rows and three measurements were taken at each plot by counting the number of rectangles more than half filled with green leaf and the fraction of intercepted PAR (f) by the canopy was determined assuming 1:1 relationship between percentage of ground cover and percentage of intercepted radiation (Tsegaye and Struik, 2003; Worku and Demissie, 2012):

$$(IPARi)=(PARi\times GCi)$$

Where: IPARi = amount of incoming PAR intercepted at ith sampling date; PARi = recorded PAR above the canopy at ith sampling date, and GC_i=ground cover of the crop at ith sampling date

The CIPAR during the growth period was determined by summing up fortnightly intercepted radiation as follows:

$$(CIPAR)=n[(IPARn.i+IPARn)/2](tn-tn.i)$$

Where, $IPAR_{n.i}$ is IPAR at sampling time $t_{n.i}$ and $IPAR_n$ is IPAR at sampling time t_n.

Statistical analyses

Data were analyzed using the general linear model procedure of SAS statistical software. Means were separated using Fisher's Least Significant Difference (LSD) test at 5% significance level.

RESULTS AND DISCUSSION

The analysis of variance and statistical significance levels of different growth parameters and CIPAR is summarized in Table 2. The result indicates that most of the growth parameters such as plant height, shoot number, leaf number, leaf area and leaf area index are significantly affected by main effects and interaction effects such as

Table 3. Summary of ANOVA table for corm number, cormels number, corm weight, cormels weight, corm length, corm diameter, marketable yield, and total yield of taro as affected by location, planting density and planting dates.

Sores of variation	Mean sum of square								
	Dry matter (kg plant^{-1})	Corm number plant^{-1}	Cormels number plant^{-1}	Corm weight (kg plant^{-1})	Cormels weight (kg plant^{-1})	Corm length	Corm diameter	Marketable yield (kg plant^{-1})	Total yield (kg plant^{-1})
Location	-	4.03**	17.91*	2.49**	1.86***	1224.87***	13.11**	8.65***	7.46***
Replication	0.16**	0.12^{ns}	1.57^{ns}	0.29**	0.42**	6.12^{ns}	1.47*	1.42***	1.41*
Planting density (PP)	0.11**	0.48^{ns}	8.02*	0.19**	0.36**	8.59*	0.18^{ns}	1.07**	2.30**
Planting date (PD)	0.03^{ns}	1.27*	5.51^{ns}	0.25***	0.19^{ns}	11.24*	1.29^{ns}	0.51*	0.71^{ns}
L*PP	-	0.73^{ns}	1.90^{ns}	0.03^{ns}	0.02^{ns}	0.65^{ns}	0.61^{ns}	0.02^{ns}	0.28^{ns}
L*PD	-	0.53^{ns}	3.09^{ns}	0.03^{ns}	0.05^{ns}	1.80^{ns}	0.54^{ns}	0.014^{ns}	0.03^{ns}
PP*PD	0.03^{ns}	0.49^{ns}	2.25^{ns}	0.07^{ns}	0.05^{ns}	1.51^{ns}	0.23^{ns}	0.20^{ns}	0.26^{ns}
L*PP*PD	-	0.22^{ns}	3.21^{ns}	0.03^{ns}	0.06^{ns}	3.60^{ns}	0.34^{ns}	0.12^{ns}	0.31^{ns}

*, **and *** where significant at P<0.05, P<0.01 and P<0.001, respectively.

location, planting density, planting dates, location by planting density and location by planting dates (Table 2). Similarly, in Table 3 the ANOVA results and significance level of main and interaction effects of treatments on taro corm and cormels yield and yield components are summarized (Table 3). The results of the interaction effects of all the growth and yield parameters considered in the study are discussed under their respective sub head in this section of the paper.

Date of emergence and stand count (%)

Date of emergence and stand count percentage were affected significantly (p<0.01) by interaction of location by planting dates. Early emergences (33.0 days after planting) and higher stand counts (91.7%) were recorded from late March planting at Areka (Table 4). In contrast, late emergence (65.3 days) and minimum stand count (47.6%) were recorded from mid-February at Areka and mid-April at Hawassa, respectively. The main reason for such variation in emergence date and stand count were due to the variability in soil texture that could affect the soil moisture holding capacity as the soil texture of the locations were 50% clay at Areka and 30% clay at Hawassa (Table 1). Similarly, the variation of rainfall between the two locations take the share for the result as the total Rainfall at Areka is exceeding that of Hawasssa (Figure 1B).

Generally, early planting in mid-February delayed the emergence of taro for more than 60 days at both locations (Table 4) whereas, late planting in late March and mid-April during onset of rainy season accelerated date of emergency both at Areka and Hawassa almost by 50 to 48% and 34 to 45%, respectively. The result assures the importance of available moisture for emergence and successive plant stand in the field as the rain was very low during February, and March at both locations (Figure 1B). The corm dormancy may also be another expected reason for such delays of the emergency as corms can remain underground and survive during unfavorable environmental conditions (Onwueme, 1999; Safo-Kantaka, 2004). On the other hand, early emergency and relatively effective plant stand coincide at Areka in late march planting. That was mainly due to availability of moisture. Though, the onset of rainfall in both site was parallel, Areka site received relatively more amount of rainfall compared to Hawassa. In addition, Areka soil texture supported to conserve moisture for emergency and successive plant stands.

Plant height

Plant height was influenced by both planting density and planting dates at the two locations. In which plant height increased as planting density increasing at both locations (Table 5) and maximum plant heights (103.71 and 82.71 cm)

Table 4. Interaction effect of location by planting dates on date of emergence and stand count.

Location	Planting date	Date of emergence	Stand count (%)
Areka	Mid-February	65.3[a]	74.9[b]
	Early March	42.5[c]	87.3[a]
	Late March	33.0[d]	91.7[a]
	Mid-April	34.2[d]	59.2[cd]
Hawassa	Mid-February	61.5[a]	62.3[c]
	Early March	54.5[b]	52.4[cd]
	Late March	40.8[c]	55.6[cd]
	Mid-April	33.8[d]	47.6[d]
Mean		45.7	66.4
LSD5%		5.95	12.3
CV		16.0	22.7

Table 5. Interaction effect of location by planting density on plant height.

Location	Planting density (plant/ha)	Plant height (cm)
Areka	15037	82.56[c]
	19607	93.311[b]
	26667	102.02[ab]
	38461	103.71[a]
Hawassa	15037	78.33 [c]
	19607	76.30[c]
	26667	78.03[c]
	38461	82.71[c]
Mean		87.12
LSD5%		9.96
CV		14.1

were recorded from maximum plant density (38461plants ha^{-1}) at both Areka and Hawassa, respectively. Form the interaction of location by planting dates maximum plant height (106.4 m) was recorded at Areka from late March planting (Table 6).

Similar result was reported by Abd-Ellatif et al. (2010) on taro, Sener et al. (2004) on maize (*Zea mays*) and in pea (*Pisun sativum*) by Saiful et al. (2002) in which plant height was increased with planting density. The result may be attributed to increased competitions for sun light radiation in higher planting density as well as an adaptation mechanism to increased level of mutual shade. However, an opposite result was also reported in pigeon pea (*Cajanus cajan*)) by Worku and Demissie (2012), in which plant height has decreased with increasing planting density. Early studies on potato crop by Allen and Wurr (1973) also revealed that planting density significantly increased the height of main stem, in which they had justified further competition for more light interception.

Shoot and leaf number per plant

Number of shoot per plant was influenced by planting density and location, but not by planting dates. Number of shoot declined as planting density increased and maximum number of shoot per plant (8.4) was recorded from the minimum planting density (15037 plant ha^{-1}), whereas minimum number of shoot per plant (6.2) was obtained from the maximum planting density (38461 plant ha^{-1}) (Table 7). Likewise, Gendua et al. (2000) and Tsedalu et al. (2014) reported the same result on taro and Masariramb et al. (2012) on potato. This could be due to competition for light radiation and limited soil nutrient in higher planting density per unit area.

Like that of shoo number, leaf number per plant was significantly ($p<0.01$) affected by planting density and location but not by planting dates. Leaf number per plant declined against increasing planting density (Table 7). The maximum leaf number per plant (34.6) was recorded from the minimum planting density (15,037 plants ha^{-1})

Table 6. Interaction effect of location by planting dates on plant height.

Location	Planting date	Plant height (cm)
Areka	Mid-February	88.5[b]
	Early March	102.0[a]
	Late March	106.4[a]
	Mid-April	84.7[bc]
Hawassa	Mid-February	78.8[cd]
	Early March	73.7[d]
	Late March	85.7[bc]
	Mid-April	77.2[cd]
Mean		87.12
LSD5%		9.5
CV		13.4

Table 7. Effect of location and planting density on shoot number, total leaf number, leaf area and leaf area index per plant.

Location	SHN	LN	LA	LAI
Areka	6.4[b]	23.2[b]	2.8[b]	7.6[a]
Hawassa	8.3[a]	35.2[a]	3.2[a]	6.7[a]
LSD5%	0.7	3	0.4	NS
Planting density				
15037	8.4[a]	34.6[a]	3.49[a]	5.3[c]
19607	7.8[ab]	30.9[ab]	3.2[a]	6.8[b]
26667	6.9[bc]	27.3[bc]	3.0[ab]	7.5[b]
38461	6.2[c]	23.9[c]	2.4[b]	9.1[a]
Mean	7.3	29.2	3.0	7.17
LSD5%	1.04	4.2	0.61	1.5
CV	24.6	25.2	35.1	36.4

SHN = Shoot number; LN=Leaf Number; LA=Total leaf area per plant; LAI = Total leaf area index, per plants.

(Table 7). Like that of shoot number, leaf number per plant declined against planting density. However, Tsedalu et al. (2014) reported that, plant density has no significant effect on leaf number per plant, but, similar with the current result, Abd-Ellatif et al. (2010) reported most of the vegetative growth including leaf number per plant influenced by planting density. Though, unlike the current result they reported that most of vegetative growth parameters including leaf number per plant increased with increasing plant density.

Leaf area and leaf area index

Leaf area per plant was affected by location, planting density and planting dates. Maximum leaf area (3.2 m^2) was recorded at Hawassa. Leaf area per plant declined with increasing planting density with maximum leaf area per plant (3.49 m^2) being recorded from the minimum density (15037 ha^{-1}) (Table 7). The reason behind this result is the limited resource availability for each plant as plant density increased limiting the amount of assimilates available for leaf development. Similar result is also reported on pigeon pea by Worku and Demissie (2012). From planting dates, Late March planting significantly influenced the leaf area compared to other planting dates. Similarly, Mare (2009) also reported that leaf area per plant was affected by planting dates. Early investigation by Nanda et al. (1995) also indicated that early planting of brassica species significantly increased leaf number per plant than the same species planted late. In this study, late March planting seems appropriate time as early emergency and maximum plant stand were recorded particularly at Areka location. That may aid for maximum interception of light and subsequent vegetative growth. Comparable report by Wajid et al. (2004) also

Table 8. Effect of planting dates on leaf area per plant.

Planting date	LA (m^2)
Mid-February	2.9^{b}
Early March	2.7^{b}
Late March	3.6^{a}
Mid-April	2.9^{b}
Mean	3.00
LSD	0.61
CV%	35.08

Means within a column followed by the same letter (s) are not significantly different

Table 9. Interaction effect of location and planting dates on leaf area index of taro.

Location	Planting density (plant/ha)	LAI
Areka	15037	4.4^{c}
	19607	5.7^{bc}
	26667	7.9^{ab}
	38461	9.0^{a}
Hawassa	15037	6.1^{bc}
	19607	9.4^{a}
	26667	5.8^{bc}
	38461	9.1^{a}
Mean		7.2
LSD5%		2.2
CV		37.0

Table 10. Effect of planting density on dry matter production and cumulative intercepted photosynthetic radiation (CIPAR MJ m^{-2}).

Planting density (plant/ha)	DMpg/plant	CIPAR MJ m^{-2}
15037	0.58^{a}	344.00^{c}
19607	0.48^{ab}	358.19^{bc}
26667	0.44^{b}	393.05^{ab}
38461	0.37^{bc}	414.83^{a}

indicate that early sowing intercepted more PAR than the late sowing probably due to longer duration in wheat under semi-arid conditions.

LAI was influenced by interaction effects of planting density and location (Table 2), but not by location and planting dates independently (Table 8). Unlike LA, LAI increased with increasing density (Table 7). From interaction of location by planting density the highest LAI (9.0 and 9.1) was recorded from the maximum planting density (38461 ha^{-1}) at both Hawassa and Areka respectively (Table 9) that was because of bulky leaf number contribution from large number of plants per unit area. Similarly, Tsedalu et al. (2014) reported maximum LAI per plant from maximum plant density in taro planting material type and population density study; Zhou et al. (2011) also found out maximum LAI in narrow plant spacing of soybean crop spacing investigation. Correspondingly, in wetland-grown taro plant populations and seedbed type studies LAI was increased with increasing density (Tumuhimbise et al., 2009).

Light interception and dry matter production

CIPAR and dry matter production (DMP) were influenced by planting density (Tables 2 and 3). CIPAR increased with increasing planting density but, dry matter production per plant decreased as planting density increased (Table 10).

Table 11. Effect of planting dates on cumulative interception photosynthetically active radiation (CIPAR MJ m^{-2}).

Planting date	CIPAR MJ m^{-2}
Mid-February	382.63^{ab}
Early March	363.33^{b}
Llate March	411.27^{a}
Mid-April	352.84^{b}
Mean	377.518
LSD	4250
Cv%	13.5

Table 12. Effect of planting dates on number of corm per plant, weight of corm, number of cormel, weight of cormel, Corm and cormel length (cm) and diameter (cm), marketable yield and total yield.

Location	Corm number	Corm weight (kg/plant)	Cormels number	Cormels weight (kg/plant)	Corm length (cm)	Corm diameter (cm)	Marketable (kg/plant)	Total yield (kg/plant)
Areka	2.24^{a}	0.96^{a}	6.4^{a}	0.9^{a}	18.7^{a}	7.56^{b}	1.9^{a}	2.1^{a}
Hawassa	1.83^{b}	0.64^{b}	5.5^{b}	0.7^{b}	11.5^{b}	8.3^{a}	1.3^{b}	1.5^{b}
LSD5%	0.22	0.08	0.7	0.11	0.74	0.27	0.17	0.22
Planting dates								
Mid-February	1.9^{bc}	0.8^{b}	6.5	0.9	14.8^{b}	7.76^{b}	1.65^{a}	1.9^{ab}
Early March	2.3^{a}	0.9^{a}	6.1	0.8	14.9^{b}	7.95^{ab}	1.66^{a}	1.9^{a}
Late March	2.1^{ab}	0.9^{a}	5.7	0.7	16.1^{a}	8.25^{a}	1.67^{a}	1.9^{a}
Mid-April	1.8^{c}	0.7^{b}	5.3	0.7	14.6^{b}	7.76^{b}	1.37^{b}	1.6^{b}
LSD	0.31	0.12	NS	NS	1.04	0.38	0.24	0.31
Cv%	26.3	24.4	29.2	34.9	12.0	8.2	25.9	29.9

On the other hand, DMP were not influenced by planting dates except the CIPAR (Table 11) where maximum CIPAR was recorded from late March planting but, significant variation was not observed among the other planting dates (Mid- February, Early march and Mid-April).

CIPAR increased with increasing planting density whereas, dry matter production decreased against planting density. However, Oluwasemire and Odugbenro (2014) in soya bean reported that higher solar radiation intercepted increased radiation use efficiency (RUE), and dry matter production under uniform planting density. That could be due to the high competition and shading effect in high planting density. Similar result was also reported by Macanawai et al.(2012) indicating that the shading effect from crops and other weeds would reduce light intensity within the crop and the reduction in biomass production.

Corm and cormels number per plant

Corm number per plant was influenced by location and planting dates (Table 3). Maximum corm numbers per plant (2.24 and 2.3) was recorded from Areka location and Early March planting respectively (Table 12). On the other hand, cormels number per plant was affected by location and planting density.

Maximum cormels number per plant (6.2 and 6.4) recorded from 26667 and 15037 plant ha^{-1} respectively. The lowest number of cormels per plant (5.1) was recorded from the maximum planting density (38461 plant ha^{-1}) (Table 13). Masariramb et al. (2012) reported that in potato crop tuber numbers were significantly affected by plant population density, in which lower number of tubers per plant was recorded from the highest density.

Though, in the current study cormels number was not influenced by planting dates, Mare (2009) reported that the number of cormels per plant significantly decreased when planting date was delayed. In the same way, Abd-Ellatif et al. (2010) also reported that early planting dates gave the highest values of weight of corm and cormels per plant under irrigation condition.

Table 13. Effect of planting density on corm number and weight per plant, and cormels, number and weight per plant , corm and cormels length and diameter, marketable yield and total yield per plant.

Planting density	Corm number	Corm weight (kg/plant)	Cormels number	Cormels weight (kg/plant)	Corm length (cm)	Corm diameter (cm)	Marketable yield (kg/plant)	Total yield (kg/plant)
15037	2.0	0.9^{a}	6.2^{a}	0.9^{a}	15.8	7.94	1.8^{a}	2.2^{a}
19607	2.2	0.8^{a}	6.0^{ab}	0.8^{a}	15.1	7.88	1.6^{ab}	1.8^{b}
26667	2.0	0.8^{ab}	6.4^{a}	0.8^{ab}	15.1	7.86	1.6^{b}	1.7^{bc}
38461	1.9	0.7^{b}	5.1^{b}	0.6^{b}	14.3	8.05	1.3^{c}	1.5^{c}
Mean	2.0	0.80	5.9	0.8	15.1	7.93	1.59	1.81
LSD	NS	0.1	1.2	0.2	NS	NS	0.24	0.31
Cv%	26.3	24.4	29.2	34.9	12.0	8.2	25.9	29.9

Corm and cormels weight per plant

Corm weight per plant was significantly influenced by location, planting density and planting dates (Tables 12 and 13). Maximum corm weight (0.96, 0.90 and 0.89 kg plant^{-1}) was recorded from Areka, 15037 plant ha^{-1} and early and late March planting, respectively. Corm weight per plant decreased as planting density increased; the minimum corm weight per plant, 0.69 kg plant^{-1}, was recorded from 384616 plants ha^{-1} (Table 13).

On the other hand, cormels weight per plant was affected by planting density and location but not by planting date (Tables 12 and 13). The highest weight of cormels per plant was recorded from the minimum planting density (15037 plant ha^{-1}) (Table 13).

Similar finding was also reported by Tsedalu et al. (2014) in which large corm weight per plant is recorded from the lowest planting density. Similarly, Abd-Ellatif et al. (2010) found out that increasing the spacing between plants from 20 to 50 cm significantly increased the weight of corm and cormels per plant. This could be due to the fact that an optimum planting density allows efficient utilization of soil nutrient and maximum light interception for more photosynthesis and dry matter accumulation in their storage organs.

Corm length and diameter

Corm length and diameter per plants were not influenced by planting density but by planting dates and location (Tables 12 and 13). Maximum corm length (18.66 cm) and diameter (8.3 cm) were obtained from Areka and Hawassa respectively. The result was similar with the result of Tumuhimbise et al. (2009) in which they found both corm parameters were not significantly influenced by planting density. However, Tsedalu et al. (2014) reported differences in mean corm length per plant due to plant density in which they found the highest mean corm length from the lowest plant density. In potato tuber, similar result was also reported by various authors in which average tuber size has been shown to decrease nonlinearly in response to increasing crop density (Knowles and Knowles, 2006; Zebarth et al., 2006). Abd-Ellatif et al. (2010) also reported the effect of planting date, intra-row spacing and their interactions on corm diameter, corm length and their ratio.

Marketable and total yield per plant

Average marketable yield per plant was significantly affected by location, planting density and planting dates (Tables 12 and 13). However, all planting dates are at par except for Mid-April. Total yield was also influenced by planting density but not by planting dates. Both marketable yield and total yield per plant decreased as planting density increased. Maximum marketable yield and total yield per plant were recorded from the minimum planting density (15037plant ha^{-1}) (Table 13). Similar finding was also reported by Mangani et al. (2015) in which marketable yield significantly increased in wider spacing.

Conclusion

The current study revealed that plant density is an important agronomic management practice to improve the productivity of root crops through enhancing the capacity of plant for light interception, and thereby dry matter production. The minimum planting density (15037 plant ha^{-1}) outscored in vegetative growth, DMP, marketable and total yield per plant. Planting date is also an important management practice; Late March planting was identified best in vegetative growth, CIPAR, DMP, marketable yield and total yield of taro. However, during the field experiment, the onset of rain was late from the usual at both locations; as a result the first planting date at mid-February took about 63.4 days in average before emergence due to extended dry season. The results of the current experiment confirm that the availability of soil moisture was more important than the time of planting.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

Hawassa University College of Agriculture and Norwegian Agency for Development Cooperation (NORHED) thankfully acknowledged for financial support. Areka Agricultural Research Center (AARC) is also acknowledged for providing planting materials and facilitating field experiment at Areka.

REFERENCES

Abd-Ellatif AA, Shehata AE, Youssef SM (2010). Effect of Planting Date and Intra-row Spacing on Growth, Yield and Quality of Taro. Research Journal of Agriculture and Biological Sciences 6(6):806-814.

Allen EJ, Wurr DCE (1973). A comparison of two methods of recording stems densities in the potato crop. Potato Research 16:10-20.

Bernardes CO, Martins CA da S, Santos F, da Rocha MJR, Xavier TMT (2011). Leaf Area, Leaf Area Index and Light Extinction Coefficient for Taro Culture. ENCICLOPÉDIA BIOSFERA, Centro Científico Conhecer –Goiânia 7(12).

Beyene TM (2013). Morpho- Agronomical Characterization of Taro (*Colocasia esculenta* L.) Accessions in Ethiopia, Plant 1(1):1-9. doi: 10.11648/j.plant.20130101.11

Central Statistical Agency (CSA) (2011). Federal democratic republic of Ethiopia Central Statistical Agency Crop production forecast sample survey, 2010/11 (2003 e.c.) (Conducted from September 12 to October 25, 2010)

Dagne Y, Mulualem T, Kifle A (2014). Development of high yielding Taro (*Colocacia esculenta* L.) Variety for mid altitude growing areas of Southern Ethiopia. Journal of Plant Sciences 2(1):50-54.

De la Pena RS, Plucknett DL (1972). Effects of nitrogen fertilization on the growth, Composition and yield of upland and lowland taro (*Colocasia esculenta* L.). Experimental Agriculture 8:187-194.

Food and Agriculture Organization (FAO) (1999). Taro cultivation in Asia and the Pacific, Food and Agriculture Organization of the United Nations, (FAO), Rome, Italy.

Gendua PA, Risimeri JB, Maima JB (2001). The effect of planting density on the marketable corm yield of taro (*Colocasia esculenta* (L.) Schott). In: Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds) Food Security in Papua New Guinea. ACIAR Proceedings, No. 99, Canberra pp. 764-774.

Gendua PA, Risimeri JB, Maima JB (2000). The effect of planting density on the marketable corm yield of taro (*Colocasia esculenta* (L.)Schott). Bubia Resarch station, National Agricultural Research Institute (NARI) Morobe PNG. Printed in: NARI pp. 764-767.

Hussain A, Azam M, SA, Waji D, Musaddique M (1999). Growth, yield and water use of lentils (*Lens culinaris*). Proc. Nat. Workshop on Water Resources: Achievements and Issues in 20th Century and Challenges for the next millennium, June 28–30, Islamabad, Pakistan pp. 207-11.

Hussain A, Nawaz M, Chaudhry FM(1998). Radiation interception and utilization by chickpea (*Cicer arietinum* L.) at different sowing dates and plant population. Agricultural Sciences 3:21-25.

Hussain A, Wajid A, Maqsood M, Ahmad A, Rafiq M (2002). Effect of drought on wheat yield and radiation use efficiency. Proc. Nat. Symp. On Drought and Water Resources in Pakistan, March 18, 2002, Lahore Pakistan pp. 75-80.

John J, Roy C, Yamakawa A, James H (2007). Hawaiian, Kalo, Past and future, Corporative Extension service, college of Tropical Agriculture and HumanNutrition, University of Hawaii at Manoa.

Knowles NR, Knowles LO (2006). Manipulating stem number, tuber set, and yield relationships for northern and southern-grown potato seed lots. Crop Sciences 46:284-296.

Macanawai AR, Day MD, Tumaneng-Diete T, Adkins SW (20012).Vegetative Growth and Development of Mikania Micrantha In Taro and Cassava Production In Viti Levu, Fiji. Pak. Journal Weed Science Research 18:377-384.

Maddonni GA, Otegui ME, Cirilo AG (2001). Plant population density, row spacing and hybrid effects on maize canopy architecture and light attenuation. Field Crop Research 71:183-193

Mangani R, Mazarura U, Matiata TA, Shayanowako A (2015). Growth yield and Quality Responces to Plant Spacing in Irish potatoes: A Review. African Journal of Agricultural Research 10(7):727-730.

Manner HI, Taylor M (2011). Farm and Forestry Production and Marketing Profile for Taro (*Colocasia esculenta* L.). In: Elevitch, C.R. (ed.). Specialty Crops for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Holualoa, Hawai'i. http://agroforestry.net/scps (Accessed on March/11/2016)

Mare R (2009). Taro (*Colocasia esculenta* L. Schott) Yield and Quality Response to Planting Date and Organic Fertilization. A PhD Dissertation Submitted in fulfillment of the requirements for the degree of Doctor of Philosophy (Crop Science) in the School of Agricultural Sciences and Agribusiness University of KwaZulu-Natal Pietermaritzburg, South Africa.

Mare RM, Modi AT (2012). Taro corm quality in response to planting date and post-harvest storage: I. Starch content and reducing sugars. African Journal of Agricultural Research 7(19):3014-3021.

Masariramb MT, Mandisodza FC, Mashingaidze AB, Bhebhe E(2012). Influence of plant population and seed tuber size on growth and yield components of potato (*Solanum tuberosum* L.). International Journal Agricultural Biology 14:545-549.

Nanda R, Bhargava SC, Rawson HM (1995). Effect of sowing date on rates of leaf appearance,final leaf numbers and areas in*Brassica campestris, B. juncea, B. napus* and *B. carinata,* Field Crops Research 42:125-134.

Ndon BA, Ndulaka NH, Ndaeyo NU (2003). Stabilisation of yield parameters and some nutrient components in cocoyam cultivars with time in Uyo, southern Nigeria. Global Journal of Agricultural Sciences 2:74-78.

Oluwasemire KO, Odugbenro GO (2014). Solar Radiation Interception, Dry Matter Production and Yield among Different Plant Densities of Arachis spp. in Ibadan, Nigeria. Agricultural Sciences 5:864-874.

Onwueme IC (1999). Taro cultivation in Asia and the Pacific. RAP Publication: 1999/16. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific. Bangkok, Thailand.

Paul B, Balaji R (2007). Interannual Variability and Ensembles Forecast of Upper Blue Nile Basin Kiremt Season Precipitation. Journal Hydrometeor 8:327-343

Purcell LC, Ball RA, Reaper JD, Vories ED (2002). Radiation use Efficiency and biomass production in soya bean at different plant population densities. Crop Science 42:172-177

Saiful IM, Rahman MA, Salam MA, Masum AS, Rahman MH (2002). Growth and vegetable pod yield of edible podded pea as influenced by sowing time and plant density. Journal Biological Science 2:706-709.

Safo-Kantaka O (2004). *Colocasia esculenta* (L.) Schott. Record from Protabase. PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale) [ed. by Grubben, G. J. H. \Denton, O. A.]. Wageningen, Netherlands: PROTA. http://database.prota.org/search.htm

Scott RK, Jaggard KW (1978). Theoretical criteria for maximum yield. Proc. 41 Winter Cong. Int. Inst. Sugar Beet Res. Brussel pp. 179-98

Sener O, Gozubenli H Konuskan O, Kilinc M (2004). The effect of intera-row spacing on the grain yield and some agronomic characteristics of maize (*Zea mays* L.) hybrids Asian Journal Plant Science 3:429-432

Tadesse Y, Tesfaye B (2010). Response of Taro to Applied Nitrogen and Potassium fertilizer Levels: Nitrogen, Potassium, Growth and Yield. VDM Verlag Dr. Muller, Germany, ISBN-13: 978-3639274288, P 104.

Tsedalu M, Tesfaye B, Goa Y (2014). 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 4(17):2224-3208

Tsegaye A, Struik PC (2003). Growth, Radiation Use Efficiency and yield potential of Enset (*Enset ventricosum*) at different site in Southern Ethiopia. Annual Applied Biology 142:71-81

Tumuhimbise R, Talwana HL, Osiru DSO, Serem1 AK, Ndabikunze BK, Nandi JOM, Palapala V (2009). Growth and Development of Wetland-Grown Taro under Different Plant Populations and Seedbed Types in Uganda. African Crop Science Journal 17(1):49-60

Uzun S (1996). The quantitative effects of temperature and light environment on the growth, development and yield of tomato and aubergine. Ph.D. Thesis, The University of Reading, England.

Wajid A, Hussain A, Ahmad A, Rafiq M, Goheer AR, Ibrahim M (2004) Effect of Sowing Date and Plant Density on Growth, Light Interception and Yield of Wheat under Semi-Arid Conditions. International Journal of Agricultural Biology 6(6):1560-8530. http://www.ijab.org

Worku W, Demisie W (2012). Growth, light Interception and Radiation use efficiency response of pigeon pea (*Cajanus cajan*). Journal of Agronomy 11(4):85-93.

Zebarth BJ, Arsenault WJ, Sanderson JB (2006). Effect of seed piece spacing and nitrogen fertilization on tuber yield, yield components, and nitrogen use efficiency parameters of two potato cultivars. American Journal Potato Research 83:289-296.

Zhou XB, Chen YH, Ouyang Z (2011). Row spacing effect on leaf area development, light interception, crop growth and grain yield of summer soybean crops in Northern China. African Journal of Agricultural Research 6(6):1430-1437.