Effect of Type of Planting Material and Population Density on Corm Yield and Yield Components of Taro (*Colocasia Esculenta* L.)

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Abstract
Field experiment was conducted to examine the effect of type of planting material and plant population density on the yield and its components during the main rainy season at Areka Agricultural Research Center from April 2006 to January 2007 in a split- plot design with three replications. The treatments included a factorial combination of two type of planting material of variety Boloso -1 and 16 densities through different arrangements (35, 50, 65, and 80cm) inter and (50, 70, 90 and 110cm) intra row spacing. The result showed that type of planting material had a significant ($p<0.05$) effect on 50% emergence, number of leaves, leaf area, weight of corm and dry matter percentage per plant and total, marketable and unmarketable yield (tha^{-1}). Corms achieved 50% emergence earlier than cormels, they also recorded higher mean height, leaf number, shoot number, leaf area, corm weight and corm diameter per plant as well as higher total and marketable yield (tha^{-1}). Plant population density had a highly significant ($p<0.001$) effects on number of suckers, corm diameter, number of corm, weigh of corm, leaf area index per plant and total, marketable and unmarketable corm yield (tha^{-1}). Total yield, marketable and unmarketable yield of corm yield increased with increasing planting density while the mean corm weight per plant decreased at higher densities. The highest average total yield ($49.85tha^{-1}$) were obtained at 25,973 plants ha^{-1} with marketable yield of $37tha^{-1}$ that is followed by $40.5tha^{-1}$ were obtained at 31,745 plants ha^{-1} with marketable yield of 27 tha^{-1}. Type of planting material and population density interaction had a significant ($P<0.001$) effect on total and marketable corm yield (tha^{-1}) with their maximum density at 25,973 plants ha^{-1}. Therefore, to maximize yield and still to properly earth up, population density of 25,973 plants ha^{-1} (35cm x 110cm) could be recommended. In conclusion, total and marketable yields were maximized at 25,973 plants ha^{-1} for both corm and cormel type of planting material for marketable and unmarketable (for planting) taro production.
Keywords: Density, Planting material, Taro, Spacing, LAI, Yield, Yield component

1. INTRODUCTION

Taro (*Colocasia esculenta*) is grown in nearly all parts of the humid tropics in more than 65 countries worldwide and serves as an important staple food and as a source of carbohydrate for inhabitants in some subtropical and virtually all tropical regions (LEISA, 2004). It is cultivated mainly in developing countries, rarely on large plantations but on small farms with little technology (Chien-Chun *et al.,* 2006). Taro ranked 14th among staple crops in 1987 in terms of volume of production (Hollyer, 1997). According to the FAO (2007) statistical report, world taro production in 2005 was over 11.7 million metric tons from an area of 1,781,270 hectare of land with global average yield of 6.5 ton/ha. The top 6 producing nations are Nigeria, Ghana, China, Cambodia, Côte d'Ivoire and Papa New Guinea, respectively (FAO, 2007). The bulk of production is in Africa, Nigeria and Ghana producing 5.1 and 1.8 million metric tons from an area of 667,000 and 270,000 hectare, respectively; however, its intensity of cultivation and highest percentage contribution to the diet occurs in the Pacific Islands (Onwueme, 1999).

In Ethiopia, a total of 26,506.36 hectares of land in 2001/02 cropping season was covered by taro (CACC, 2003) and the production is estimated to be over 190,000 tons (MARD, 2005). Out of the total taro area cultivated in 2001/02 cropping season, the bulk of production of taro (20,100.48 ha) was in Southern Nations Nationalities and Peoples' Regional State (SNNPRS), followed by Oromia (6,147.87 ha), Gambella (231.84 ha) and Benishangule Gumuz (9.36 ha) regions (CACC, 2003). In Wolaita zone of the SNNPRS, 29.59% of the crop area was under sweet potatoes, potatoes and taro each covering 66.5%, 18.5% and 14.2% of the production area, respectively. The total area under taro cultivation in the zone was 4,202.46 ha, accounting for 16% of the country and 30% of the regional share (CACC, 2003). Farmers in Wolaita have identified about seven different clones of taro locally known as *Gerezua*, *Shishia*, *Yittria*, *Moliya*, *Tawayia*, *Gesa*, *Woldua* and *Kawo Boina* (cultivar *Kawo Boina* belonging to the genus *Xanthosoma)*, on the basis of morphological, phenological, agronomic and quality traits, and fitness into cropping systems and medicinal values (Asfaw, 2006; Simon, 1992).

At present, there has been an increase in the area of production of taro in SNNPR, and the level of dependence on sweet potato and enset crop is shifting to maize and taro in Wolaita (Asfaw and Waga, 2004 unpublished) due to enset bacterial wilt, sweet potato butterfly and the introduction of high yielding taro variety, Boloso-1. In Ethiopia, taro is highly prized and is a dominant staple food crop in subsistent sector and an important source of cash income (Simon, 1992). The corms and cormels (in Ethiopia) as well as the leaves are the main economic part of taro plant are rich in starch and eaten in a manner similar to potatoes; boiled, baked, roasted, fried or as a basis for soups (Kay, 1987). In Ethiopia, corm/cormels boiled and eaten similar to potato, mixed with other vegetables, butter and garlic (Asfaw, 2006). Corm/cormels are considered as a good source of carbohydrates which considered as excellent for people with digestive problems, for people with allergies, such as lactose intolerance, and as canned baby foods (Matthews, 2004). In comparison with potato, taro corm has a higher proportion of protein (1.5-3.0%), calcium, and phosphorus; it has a trace of fat, and is rich in vitamins A and C (Hsiu-Ying Lu *et al.,* 2005). Oxalic acid may be present in the corm and especially in the young leaf (Matthews, 2004). Traditionally taro is vegetatively propagated plant species but some species flower and produce seeds naturally while others can be induced to produce seeds by spraying gibberelic acid (Tyagi and Deo, 2005), in some clones flowering is sporadic and the seed are tiny (Jill, 1990). Types of planting materials that are used for propagation of taro production are: side suckers, small corms (unmarketable), huli i.e. the apical 1-2cm of the corm with the basal 15-20cm of the petioles attached; corm pieces (resulting when large corms are cut into smaller pieces) and whole corms (Onwueme, 1999). Because of the profusion of buds on the corm and cormel, taro conventionally established from intact corms, intact cormels, or piece of corm and cormels (Onwueme and Sinha, 1991). In Wolaita and other taro growing areas in the country, there is inadequate supply of planting material as the corm and cormels are often fully consumed by the family, leaving too little for planting material (Simon, 1992).

The national average yield of 8tha^{-1} (CACC, 2003) is by far greater than the global average yield of 6.5tha^{-1} and lower than Asian average (12.6tha^{-1}) (Silva *et al*., 1992). Current global yield levels in taro production are relatively low. However, research conducted in different parts of the world (Goenaga and Chardon, 1995; Silva *et al.,* 1992) demonstrates that under intensive commercial management taro yields between 21tha^{-1} and 70tha^{-1}. One of the highest yielding cultivars (Boloso -1) gave an average fresh corm yield of over 67tha^{-1}, considerably exceeding the national average (Asfaw and Waga, 2004, unpublished). This demonstrates that taro yield obtained by farmers is far below the crop potential. The productivity of crops in general and taro in particular in farmers' fields are affected by a number of factors such as soil fertility, size of planting material, variety, weed, leaf area, suckering, type of planting material, population density, etc. Among these, types of planting materials and population density are the most important in the study area. Simon (1992) reported that density is an important factor, which governs corm yield of taro. Close spacing of the plants increases the production of the corm yield per unit of land up to a certain point but decreases the corm yield and leaf area per plant and the contribution of the cormels to the yield. Widely spaced planting increases the yield per plant and increases the number of corm and also leaves space for weeding, soil dressing and intercropping (Onwueme and Sinha, 1991). However, it is important to optimize plant population density for taro to maximize its yield that would contribute to food security and income generation.

In Ethiopia, some studies have been conducted on the effect of plant population density and type of planting material of taro on yield in few locations (Jimma and Areka) but there is no sufficient information on the yield response of taro to population density and type of planting material for different agro ecological zones of the country (Edossa *et al*., 1995; Simon, 1992). The recommendation of 40,000 plant ha^{-1}, (50cm x 50cm) spacing has been used for the variety Boloso–1 in Areka area. However, this density was recommended without considering type of planting material and was also not acceptable by farmers as farmers said it is narrow (Personal communication). Elsewhere in the Asian Pacific Onwueme and Sinha (1991) recommended spacing results of 60 cm between plants and between rows (27,660 plants per ha) for optimum production of taro. Such differences show the need for determining plant population density for optimum yield of taro. The main objective of this study was therefore, to determine the effect of type of planting material and plant population density that maximize taro corm yield of improved variety Boloso- 1 grown in Wolaita zone.

2. Materials and Methods

2.1. Description of the Study Area

A field experiment was conducted during the 2006-cropping season at Areka Agricultural Research Center (AARC), which is located in Southern Nations Nationalities and People's Regional State (SNNPRS), Wolayita zone. It is located at 410 km south of Addis Ababa and 3 km from Areka town, found at 7°04" 96'N latitude and 37°41".330'E longitude and altitude of 1830 meters above sea level (m.a.s.l). The soil at the center is formed from pyroclastic rocks and clayey in texture (Abayneh, 2003). The mean annual rainfall is 1659.1 mm and has a bimodal pattern that extends from March to September. The mean peak rainy months are April, August and September (190.4 mm, 215.7mm and 171.5mm, respectively). The mean annual minimum and maximum temperatures are 15^{o}C and 26°C. November is the coldest month whereas March is the hottest.

2.2 Experimental Detail

2.2.1 Experimental material and design

The treatments consists of (i) four inter (50, 70, 90 110cm) and intra (35, 50, 65,80cm) -row spacings (ii) two types of planting material (corm and cormels). The experiment was laid out as a split–plot design with factorial experimentation with three replications. Two type of planting materials and sixteen possible spacing combinations were randomly arranged in the main plot and sub-plot, respectively. The sixteen spacing arrangements (treatments) used were presented in table 1.

The variety used was Boloso-1, which is a recently released variety from Areka Agricultural Research Center (AARC) in 2004. The variety is dasheen type. It was planted on 25 April 2006. Each replication contained two main plots (planting materials) and sixteen sub plots (spacing combinations) from which the inner four rows were sampled. The experiment was surrounded by two rows of guard plants. Each plot differed in total area depending on the intra and inter- row spacing. The gross plot size also varied, each consisting of six rows and contained different number of plants, the smallest and the highest number of plants per hectare was 13,363 and 57,143, respectively.

2.2.2 Cultural practices

Planting materials used were fresh mother corm and cormels of variety Boloso-1 obtained from Areka Agricultural Research center (AARC). They were harvested from plants of the 2005/2006 cropping season. In order to facilitate sprouting, corm and cormels were dug out and left under shade (open air) and planted 10 days later. Uniform corm and cormels sizes were selected visually excluding over and under sized corm and cormels. No fertilizer was applied throughout the growing season. The experimental area was hand weeded as necessary.

The land was deep plowed and disked with tractor and then oxen plowed and finally leveled with manual labor. Incidence of disease, insect damage, frost, and storm did not occur except unusual extended rainfall and few occurrence of mole rat (*Heterocephalus glaber*). A onetime harvest was made on 2 January, 2007. Both pre-harvest and post harvest on Plant height (cm), Number of green (functional) leaves per plant, Leaf area per plant (cm^2),Maximum leaf length (Lx),Maximum leaf width (Wx),Leaf area index (LAI),Corm length (cm),Corm diameter (cm), Number of corm, Corm fresh weight per plant (g $plant^{-1}$),Marketable yield (tha^{-1}),Unmarketable yield (tha^{-1}), Corm dry matter percentage and Yield per hectare (tha^{-1}) were recorded.

2.2.4 Statistical analysis

Analysis of variance was conducted using SAS programs (SAS Insti., 2000). The experiment was analyzed as a split- plot design with main plot planting materials (Pm) and sub plot of spacings (Sp). A probability level of $p \leq 0.05$ was considered to be statistically significant and significant means were separated using Tukey's - test.

3. RESULTS

3.1 Date of 50% Emergence

Type of planting material significantly ($p \leq 0.05$) affected date of emergence. Corms achieved 50% emergence 32.9 days after planting (DAP) whereas cormels at 35.6 DAP (Table 4). Neither population density nor their interactions had significant effect ($p \leq 0.05$) on date of 50% emergence.

3.2 Plant Height

Plant height increased from a minimum of 39.18cm at two months after planting (MAP) to a maximum of 80.79cm at 7MAP; thereafter, it declined (figure 1). Analysis of variance revealed that plant height was affected significantly ($p \leq 0.05$) by source of planting material at 2, 4, 5, 6, 7, 8 and 9 MAP. Corm recorded a significantly high mean height per plant at all moths after planting (MAP).

Plant population density had no significant ($p \leq 0.05$) effect on plant height at all MAP. The height of plants differed very little in relation to density (figure 1). There was no interaction effect of plant population density and type of planting material on plant height.

3.3 Number of Leaves

Type of planting material had significant ($p \leq 0.05$) effect on leaf number per plant. Plants grown from corms recorded significantly higher number of leaves throughout the growing period except at 9 MAP (Table 2). The magnitude of the difference in mean number of leaves per plant from the two sources of planting materials was highest at 3 (4.03 leaves), 4 (4.46), 6 (4.63) and 8 (3.65) MAP. It was also observed that corms begin to develop leaves and suckers earlier than cormels due to difference in date of 50% emergence. Similarly, the experimental plots planted with corm had greater number of active (living) leaves than cormel plots. The number of leaves increased and reached maximum 5MAP and declined thereafter (Figure 2).

Plant population density had no significant ($p \leq 0.05$) effect on leaf number per plant. However, highest values per plant were recorded at densities of 57,143 (2, 3 and 6 MAP), 17,093 (4 and 8 MAP) and 13,363 (5, 7 and 9 MAP) plants/ha (Table 2). Overall, maximum number of leaves was recorded at five MAP and the highest (21.57) and lowest (14.23) mean numbers of leaves per plant were recorded at densities with 13,363 and 40,816 plants ha^{-1}, respectively. There was no interaction effect of plant population density and type of planting material on leaf number per plant.

3.4 Number of Shoots

Number of shoots per plant responded significantly ($p \leq 0.05$) to the type of planting materials at 2, 3 and 4 MAP. Corms recorded higher mean value at 2, 3 and 4 MAP (Table 3). There was little shoot development during the first two month after planting (Figure 3). Thereafter, there was an increase in number of shoots, attaining a peak at about 7MAP for both type of planting materials. After the 7th months, there was no further increase in number of shoots. Shoot number per plant was significantly ($p \leq 0.05$) affected by population density at 2, 5, 6, 7 and 9 MAP. At 3 MAP, the highest mean shoot number per plant was recorded at 28,570 plants ha^{-1}. At 5, 6, 7, and 9 MAP, the highest mean values were recorded at 13,363 plants/ha (Table 3). Shoot number per plant was not affected by density at 2, 4 and 8 MAP. Overall, the highest mean shoot number per plant (6.17) was recorded at 13,363 plants ha^{-1} at 7 MAP. There was no interaction effect between plant population density and type of planting material on number of shoots.

3.5 Leaf Area and Leaf Area Index

Type of planting material had a significant effect ($p \leq 0.05$) on leaf area per plant. Corm had scored a significantly higher mean leaf area per plant (4954.2cm^2) than cormels (3, 995.7 cm^2) (Table 4). Type of planting material had no significant ($p \leq 0.05$) effect on LAI.

Population density had no significant ($p \leq 0.05$) effect on leaf area per plant. However, leaf area per plant has shown an increasing trend with the decrease in plant density (Figure 4). Plant density had a highly significant effect ($p \leq 0.001$) on LAI per plant . The highest LAI per plant was recorded at the maximum density (57,143 plants ha^{-1}); the value decreased with decreasing density (Figure 4).

3.6 Corm Number per Plant

Type of planting material had no significant ($p \leq 0.05$) effect on mean corm number per plant . However, mean corm number per plant was slightly higher for corm than cormel (Table 5). Plant density had a highly significant ($p \leq 0.001$) effect on corm number per plant . The highest (13.03) and lowest (8.6) mean corm number plant were attained at 13,985 and 57,143 plants ha^{-1}, respectively (Table 5).

3.7 Corm Length and Diameter

Planting material had no significant ($p \leq 0.05$) effect on corm length. Nevertheless, plants grown from corm produced slightly longer (mean =11.15cm) corms than from cormels (Table 5). Similarly, density had no significant ($p \leq 0.05$) effect on corm length . However, there were differences in mean corm length per plant among different density level. The highest mean corm length was recorded at 13,888 plants ha^{-1}. This was 4 % higher than the lowest value (9.37cm) scored at 40,000 plants ha^{-1}. Mean corm diameter per plant was not affected significantly ($p \leq 0.05$) by planting material; however, it was highly and significantly ($p \leq 0.001$) affected by density . Corm diameter was highest (7.34) unit at 18,181 plants ha^{-1} (Table 5). It started to decline both at higher and lower density. Mean of the diameter/length ratio (DLR) was not affected significantly ($p \leq 0.05$) due to type of planting material. However, there are variations in the mean corm length/diameter ratio in relation to density. The lowest (0.57) DLR value was recorded at 40,816 plants ha^{-1}; this value was 4% lower than the highest DLR (0.67) recorded at 40,000 plants ha^{-1}

The interaction effects of planting material and density on corm length, diameter and DLR were non significant ($p \leq 0.05$).

3.8. Corm Weight and Dry matter Percent.

Type of planting material had a highly significant ($p \leq 0.01$) effect on average corm weight per plant . Corm recorded the highest mean weight of corm per plant than cormels (Table 5). Similarly, plant population density had a highly significant ($p \leq 0.01$) effect on corm weight per plant. The highest corm weight per plant (1582g) was recorded from 13,888 plants/ha. Corm weight increased with decreased plant density, the lowest corm weight per plant (833.7g) being obtained from 40,816plants ha^{-1}. The percentage dry matter of corm did not differ significantly between plant population densities; however, the type of planting material had significant ($p \leq 0.01$) effect on dry matter percentage. The average mean dry matter percentage was 36.06 and 35.30 for corm and cormel type of planting material, respectively (Table 5).

The interaction effects of planting material and density on corm weight and dry matter percent were not significant ($p \leq 0.05$) .

3.9 Total, Marketable and Unmarketable Yield of Taro (t/ha)

The type of planting material had a significant ($p \leq 0.05$) effect on total and marketable (> 250g) yields . The marketable (>250g) and total yields obtained from corm were significantly higher than cormel (Table 6). The magnitude of yield difference between corm and cormel was highest for total yield (8.8t/ha) than marketable (7.22) yield per hectare. Type of planting material had no effect on unmarketable (<250g) yield. However, corm gave relatively higher (5.88 tha^{-1}) unmarketable yield than cormels (4.29tha^{-1}). Plant population density also had a highly significant effect on total yield per hectare. The highest total yield (49.85tha^{-1}) was recorded at 25,973 plants ha^{-1} (Table 6). Total yield decreased both at higher and lower plant densities. Plant population density had a highly significant ($p \leq 0.001$) effect on marketable (>250g) yield per hectare . Similar to total yield marketable yield also decreased at both higher and lower densities. The highest (36.96tha^{-1}) was recorded at 25,973 plants

ha^{-1}. Density had a highly significant ($p \leq 0.001$) effect on unmarketable (< 250g) yield per hectare . The highest unmarketable yield (13.68tha^{-1}) was recorded at 31,745 plants ha^{-1}.
Yields of the two categories (total and marketable yield) were very high at higher densities, reached a maximum at 25,973 plants ha^{-1} and start to decline. Whereas the unmarketable yield were maximum at 31,745 plants per hectare (Table 6).

3.10 Association among Yield and Yield Components

Correlation of yield and yield components among themselves is presented in Table.7.
Leaf area was significantly ($p \leq 0.001$) and positively correlated with number of leaves ($r = 0.42$), plant height ($r = 0.39$), number of shoots ($r = 0.35$) number of corm ($r = 0.33$) and weight of corm ($r = 0.26$). Weight of corm per plant was significantly ($p \leq 0.001$) and positively correlated with number of leaves ($r = 0.28$), plant height ($r = 0.30$) number of corm ($r = 0.54$), corm diameter ($r = 0.47$) and leaf area ($r = 0.36$), per plant. Whereas, corm number per plant was significantly ($p<0.01$) and positively correlated with number of shoot ($r = 0.20$), corm diameter ($r = 0.36$) and LA ($r = 0.33$). Total corm yield (t/ha) was significantly ($p \leq 0.001$) and positively correlated with leaf area index ($r = 0.51$) and plant height ($r = 0.47$).

4. DISCUSSION

4.1 Size and vigor of Shoots

The type of planting material significantly ($p \leq 0.05$) affected plant height, number of leaves of taro and leaf area. Plants grown from corm gave taller shoots, higher leaf number and leaf area than plants grown from cormels. The finding of the present study agree with those reported by Johnston *et al.* (1997) who found significant difference between huli and tissue cultured plants; maximum 14 leaves 15 weeks after planting and 20 leaves 31WAP for huli and tissue culture plants, respectively.

The possible reason for this may be early emerging plants are likely to be more competitive than later emerging plants due to the development of size bias and resulting asymmetric competition. The greater size and vigor of plants from corm can be associated with the fact that corms establish faster than cormels (Table 4). Early canopy development (radiation capture) higher LA and plant height values at 2 MAP (Table 4 and figure 1). More assimilates from corm accounted for the increased size and vigor of plants than cormels.

Density had no effect on shoot length (plant height) and leaf number per plant. The non-significant effect of population density on number of leaves per plant in this experiment agreed with the report of Shih and Snyder (1984) where an increase in trend on leaf number during the early growth (2 MAP) was obtained maximum at 4 MAP with 0.2m plant spacing whereas leaf number at 0.4m and 0.6m plant spacing reached maximum 6 MAP; the number of leaves near the end of growth season reached a similar number in all plant densities. On the contrary, Gill *et al.* (2005) obtained higher number of leaves per plant (8.1) at a density of 74,000 plant ha^{-1} compared to the lowest densities. The finding differs from the report of Gendua *et al.* (2000) who found that plant density significantly affected plant height of taro. They found 10,000 plant ha^{-1} gave taller plant than the 40,000 plant ha^{-1}. Moreover, Igbokwe and Ogbonnaya (1981) obtained that plant height increased with increasing intra row spacing i.e. decreased densities with the application of 40 kg N ha^{-1}.

In most plants (e.g. maize), shoot growth (height, leaf number) reach at an optimum density; further increase in density is associated with decrease in individual plant or stem size. Higher plant densities also had a greater number of vegetative shoots; however, plots with higher initial stand densities reached equilibrium much faster than plots with lower stand densities (**Springer** *et al*., 2003). In this study, plant height and number of leaves were the same at all plant densities. The deviation in the pattern of shoot growth observed in taro can be explained by the fact that vertical growth of shoots length of the petioles, sucker production (branching nature of taro) at lower densities, plants formed more shoots than those at higher densities.

Population density has a positive and significant ($p \leq 0.001$) effect on (LAI) (Appendix V). LAI was high at highest density (2.12) and decreased with decreased density. The finding is in agreement with those reported by (Shih and Snyder, 1984) who found that higher LAI (2.15) at maximum density. On the other hand, Ezumah (1973) obtained and concluded that for optimum corm yield, LAI approached 3.

4.2 Number of Shoots per Plant

Plants raised from corm produced more shoot number per plant than cormel (Table 3). Higher shoots number was produced at 3, 5, 6 and 7 MAP. According to Miyasaka ***et al.* (2003),** root and shoot development with initiation of corm development were observed during one to four months. In this study, corm produced significant higher number of shoots at 2, 3 and 4 months (Table 3). The higher number of shoots difference at this early stage of growth observed between corm and cormels may be due to the number of shoots sprouted initially from corm.

Numbers of shoots pre plant tend to increase as plant density decreases. The maximum numbers of shoots per plant were obtained at 13,363 plant ha^{-1}. The finding is in agreement with Gregory (2004) who obtained that closer spacing significantly reduced the number of shoots per plant, mean maximum (4.4) and minimum (4.0) numbers of shoots were obtained from 17,700 and 33,055 plants ha^{-1}, respectively. The works of

Gendua *et al.* (2000) also corroborate the result of this study as they found a significant higher average of three basal suckers (shoot) per plant at the higher (40,000 plants ha^{-1}) who concluded that number of shoot per plant decreased significantly with increased plant densities. Similarly, Ezumah (1973) also reported that the contribution of sucker corms to yield increased as plant population decreased. The increased in shoot (sucker) number with decreased in density may be due to greater amount of available assimilates for below ground and the availability of more nutrient, moisture and low competition for light at low densities.

Shih and Snyder (1984) suggest that when suckers (shoots) form leaves with complete photosynthetic ability, they synthesize their own nutrients. The contribution of corm to more number of shoot per plant and the significant correlation between leaf number and shoot number (r = 0.71), shoot number and number of corm (r= 0.21) and shoot number and weight of corm (r = 0.26) obtained in this study can be explained by the relative earlier shoot emergence rate, number of daughter corm and cormel formation less than three months and also the inherent characteristics of corm and cormels in relation to shoot formation and sprouting.

4.3 Number of Corm per Plant

Planting materials (corm and cormel) had no significant effect on number of corm per plant. This finding is in agreement with those reported by Edossa *et al.* (1994) who found that using different taro propagules (corm, cut corm and cormel) has no effect on number of corm. On the contrary, Khalafalla (2001) obtained seed size of potato tuber significantly affected number of tuber per plant and number of stems per plant. The smaller variation in number of corm per plant may be due to uniformity of planting material used in this study. Plant population density had significantly affected number of corm. At higher plant density, number of corm decreased and at low densities corm number per plant increases. The result agree with those reported by Ellison *et al.* (1989) in Brazil, who found that maximum production of corm/plant was obtained at lower density of 6,700 plant ha^{-1}. Also, Edossa *et al.* (1994) obtained significant increase in number of corm per plant at lower densities. On the contrary, Safo *et al.* (1991) obtained that density had no significant effect on number of corm per plant. In this study density had significant effect on corm diameter. Higher diameter of corm was obtained at density of 18,181 plants ha^{-1}. On contrary, to this study Safo *et al*. (1991) and Edossa *et al.* (1994) found that spacing had no significant effect on diameter of the corm. The inverse relationship of number of corm per plant and density in this study may be associated with the number of shoots per plant supported by the significant correlation between number of corm and shoot number (r=0.36). Number of corms is an important determinant of the multiplication ratio. Per plant basis, maximum corm number (13) was attained at 13,985 plants per hectare.

4.4 Corm Size

Weight of corm and dry matter content of corm were affected significantly ($p<0.05$) by type of planting material. Plants grown from corm gave the highest average corm weight (1283g) than cormels (1028.73g). The result agreed with that of Khalafalla (2001) who reported that seed tuber size of potato (whole, half and farmer's seed piece) affects the marketable tuber weight. The highest corm weight obtained from corm can be explained by the fact that plants grown from corm attain greater number of leaves at relatively early stage of growth and may also be related with size advantage i.e. source/ sink relationship. This is also be reflected in the higher significant correlation observed between number of leaves and number of corm (r = 0.46), number of corm and weight of corm (r = 0.54) leaf area and number of suckers (r = 0.66).

Plant density had significant effect on corm weight per plant. At higher plant density, corm weight per plant decrease and total yield ha^{-1} increased, while the reverse is true at low densities. The highest weight of corm per plant (1.58kg) was obtained at the lowest densities (13,888 and 13,363 plants ha^{-1}). The result of this study agree with that of Gendua *et al*. (2000) who reported that the higher mean corm weight per plant (839g) was obtained from 10,000 plant ha^{-1} and reduced significantly at all plant densities above 10,000 plant ha^{-1}. In addition, Edossa *et al.* (1994) also found a significantly increased corm weight with decreased densities. De La Pena (1978) also reported that corm and cormel weight was inversely related to the number of plants per hectare in both upland and lowland taro. On contrary, Schaffer *et al.* (2005) and Adriano *et al.* (1986) reported that plant density had no significant effect on average corm and cormel weight per plant, respectively. The decreased in corm weight with increasing densities observed in this experiment may be due to lesser plant competition for growth resources per plant. The average dry matter percentage and diameter length ratio of Boloso-1 in this experiment was 36.7% and 0.63, respectively. Diameter/length ratio of 0.6 to 0.85 (oval) and 0.85 to 1.0 (round) shapes are the most acceptable than "dump ball" shape (0.35 – 0.5) (Gregory, 2004). Percent dry matter of corms of 20% is considered to be the minimum acceptable to consumers and dry weight of higher than 40% is considered as poor eating quality (Miyaska *et al*., 2001). The results showed that, variety Boloso-1 fulfill some quality parameters, which indicate the potential of this variety for food security, income generation and commercialization.

4.5 Total, Marketable and Unmarketable Yield (tha^{-1})

Type of planting material significantly ($p\leq0.05$) affected total and marketable yield of taro, with plants grown from corm giving the higher average total ($58.71 tha^{-1}$), marketable ($46.36\ tha^{-1}$) and unmarketable yield ($12.35 tha^{-1}$) than those from cormels. The finding is in agreement with report by Singh and Singh (2004) who obtained the highest mean yields of 15.36 tha^{-1} and 14.33 tha^{-1} using corm and cormel, respectively. Edossa *et al.* (1995) found that the use of corm markedly increased total corm yield per unit area than cut corm and cormel. The result of this study agrees with Purewal and Dargan, (1957) who obtained that yield was highly correlated with plant height and LAI, which were correlated with each other. The significant effect of type of planting material on total and marketable yield in this study explained by the early rate of establishment and higher plant height achieved from corm planting material which intern facilitate early canopy closure, efficient capture of solar radiation, nutrient absorption and weed suppression. This is further supported by the significant and positive correlation of yield with plant height (r=0.47) and leaf area index (r= 0.51).

Plant densities significantly ($p \leq 0.001$) affected corm total yield, marketable and unmarketable yield of taro. With increased density, yield/ha decreased. The highest and lowest yield obtained was 49.85tha^{-1} at 25,973 plants ha^{-1}. The finding is in agreement with the result obtained by Gendua *et al*. (2000) who found total yield of taro increased with plant density, showing significant increases at 40,000, 80,000 and 160,000 plant ha^{-1} over the base 10,000 plant ha^{-1}. Edossa *et al*. (1994) also reported that maximum taro yield was obtained from the density of 47,666 plants ha^{-1}. These further supported by Onwueme and Charles (1994) who concluded that maximum yield per hectare can be obtained as spacing is decreased to as low as to 30cm x 30cm; however, further increase as high as (109,000 plant ha^{-1}), the amount of planting material is enormous and the net return per unit of planting material is low. On the contrary, Safo *et al*. (1991) found that spacing had no significant effect on corm yield of *Xanthosoma* and C*olocasia.*

In the present study, the highest marketable yield was obtained at 25,973 plants ha^{-1}; the percentage of unmarketable yield was higher at higher plant population densities, which is in agreement with the report of Gendua *et al.* (2000), the separate grade >250g as marketable and < 250g and diseased one considered as unmarketable. He also obtained that the highest first grade marketable and second grade corm yields were obtained at 80,000 plants ha^{-1}. As plant population density increases the percentage of unmarketable yields increased which were 15% and 43% at 80,000 and 160,000 plant ha^{-1}, respectively. The percentage of unmarketable yield was higher at higher plant population densities. On the contrary, Zarate *et al.* (2000) obtained that percentages of marketable corm were not affected by plant density. As density increases, yield per hectare increased. The significant and positively correlation of total corm yield with LAI (r = 0.51) and plant height (r = 0.41) can be explained by the increased number of plant per unit area. This also further reflected by the higher correlations observed between corm diameter and weight of corm (r = 0.47), weight of corm and number of corm (r =0.54), number of shoots and LA (r = 0.35), number of shoot and number of corm (r = 0.26) per plant. In agreement with this Enyi (1967) obtained that yields of corms were positively correlated with LAI.

In Wolaita and elsewhere in the country, there was no distinction between marketable and unmarketable yield of taro. Farmers classify the corm into two groups: corm used for consumption and for market, and corm used for planting for the next season. Farmers select very small corms of approximately < 50g and extra large corm for planting purpose (personal communication). Plant population density significantly affected marketable corm and corm used for planting purpose.

In this study, corm type of planting material performs better than cormel. The highest average total (49.85tha^{-1}) and marketable (36.96tha^{-1}) yield obtained at a population density of 25,973 plants ha^{-1}, which performed better than the other densities. The percentages of unmarketable yield were higher at higher densities. Further increase in density above 25,973 plants ha^{-1} decrease yield ha^{-1}. Farmers around Areka in any case favor wider spacing especially for variety Boloso –1, around homestead with the application of home waste. They use 75cm x 100cm; both are wider (13,333 plants ha^{-1}) than the recommended spacing (50cm x 50cm) 40,000 plants ha^{-1} (personal observation). The finding of this study are (110cm inter row spacing) was closer to the inter row spacing (100cm) used by farmers around Areka. To maximize taro corm yield, farmers must use narrow plant spacing. Therefore, for maximum yield and economy of planting material, farmers should use 25,973plants ha^{-1} (35 x 110cm) spacing.

4.6. Optimum Density

In this study increasing density up to 25,973 plant ha^{-1} increase yield. Corm number continued to increase above this density. As a result mean corm weight per plant decrease with increasing population density. Corm number and weight are important in taro production. The former affect the multiplication rate of the crop the later is yield. Growers make decision on the bases of weight of corm > 250g for consumption; those < 250g for planting (Gendua *et al.,* 2000). In the present study, maximum yield was attained at 25,973 plants ha^{-1}. At this density, both economical (marketable) and unmarketable that can be used for planting are achieved. Further increase in density resulted in decrease with consumable corm yield while the unmarketable portion remained unchanged. Since farmers need to ensure both high yield and used a $1/10^{th}$ of this amount for planting, both needs are attained at this density.

5. SUMMARY AND CONCLUSION

The productivity of crops in general and taro in particular in farmers' fields are affected by a number of factors such as soil fertility, size of planting material, variety, weed, suckering, type of planting material, population density (spacing) and the like. Among these factors, type of planting materials and population density have been investigated and found to influence productivity of taro in many countries. In Ethiopia, farmers who grow potatoes give less regard to optimal plant population (Endale and Gebremedehen, 2001), which seems also true for other root and tuber crops including taro. Moreover, the effect of type of planting material (corm and cormels) and population density on yield and yield components of newly released and high yielding variety Boloso-1 on the study area is not known. An experiment was conducted at Areka from April 2006 to January 2007 with two types of planting material (corm and cormel) and four different inter-rows (35, 50, 65 and 80cm) and intra-rows (50, 70, 90 and 110cm) spacing in a split -plot design with three replications. The treatments included factorial combination of two types of planting material as main plot (corm and cormels) and sixteen plant densities as sub plot treatment. Data on vegetative and yield attributes were examined to determine the response of taro using different planting material and densities.

The result revealed that planting material had significant ($p \le 0.05$) effect on 50% emergence, plant height, number of leaves, number of shoot, weight of corm, dry matter percentage per plant, and marketable and total yield per hectare. Corm type of planting material recorded higher value for the parameters studied. Increasing density highly and significantly ($p \le 0.001$) increased shoot number, LAI per plant and total, marketable and unmarketable yield per hectare while, it is significantly decreased number of corm and weight of corm per plant. Type of planting material and spacing interaction had a significant ($p \le 0.001$) on total and marketable yield per hectare with their yield at 25,973 plants ha^{-1} (35cm x 110cm) for both type of planting material. In this study corm yield per unit area were maximized at higher densities. However, average shoot number, number of corm and weight of corm per plant were maximized at lower densities. The result of this study revealed that for both marketable and unmarketable yield plant population density of 25,973 plants ha^{-1} is most convenient.

ACKNOWLEDGMENT

I would like to express my special thanks to my major advisor Dr. Bizuayehu Tesfaye for his valuable guidance, encouragement, unreserved support and comments. I also extend my gratitude towards the Staff of AARC for treating me as one of the staff and the constrictive support and the technical assistance.

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Table 4. Spacing and plant population density of taro used in the experiment.

Spacing (Centimeter)	Plant population density (Plants/hectares)	Spacing (Centimeter)	Plant population density (plants/hectares)
80 x 110	13,636	80 x 50	25,000
80 x 90	13,888	35 x 110	25,973
65 x 110	13,985	50 x 70	28,570
65 x 90	17,093	65 x 50	30, 769
80 x 70	17,857	35 x 90	31,745
50 x 110	18,181	50 x 50	40,000
65 x 70	21,977	35 x 70	40,816
50 x 90	22,222	35 x 50	57,143

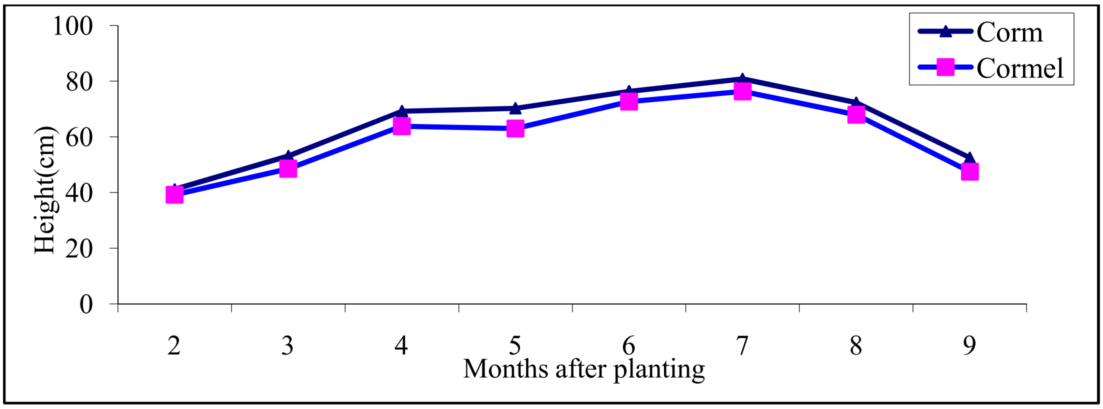

Figure 2 Mean height of taro plants from corm and cormel at different months after planting.

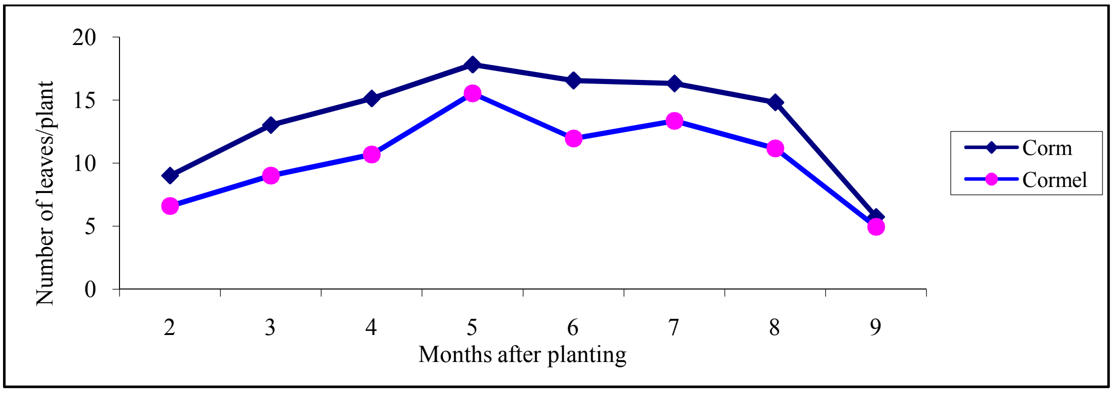

Figure 3 Mean leaf number per plant of taro from corm and cormel at different months after planting

Table 5 Mean leaf number per plant as affected by type of planting material and population density at different months after planting.

Treatment	**Months after planting**							
	2	3	4	4	5	6	7	9
Corm	9.02a	13.04a	15.14a	17.84a	16.58a	16.33a	14.83a	5.74
Cormel	6.61b	9.01b	10.68b	15.54b	11.95b	13.36b	11.18b	4.954
LSD 0.05	0.6241	1.179	1.335	1.588	1.201	1.045	1.117	NS
Densities								
13,363	7.95	11.37	13.30	21.57	14.6	17.41	13.23	6.73
13,888	8.05	12.60	12.60	17.60	14.37	15.27	12.93	6.03
13,985	7.40	9.97	12.50	18.20	13.65	15.18	12.17	4.70
17,093	8.78	10.17	16.80	17.33	17.18	16.57	15.80	4.97
17,857	7.68	10.90	13.67	16.33	14.5	14.78	13.23	5.73
18,181	7.25	8.90	12.73	16.23	13.61	14.62	13.00	5.50
21,977	7.12	9.97	12.30	18.60	13.27	15.48	12.37	5.87
22,222	7.87	12.10	12.23	16.37	13.9	14.38	12.40	5.30
25,000	7.57	12.83	11.10	16.63	13.17	14.04	11.43	5.83
25,973	7.58	10.13	12.30	16.30	13.73	14.38	12.73	5.30
28,570	8.78	12.67	13.57	16.80	15.57	15.47	14.13	5.10
30,769	7.13	9.97	12.23	15.30	12.75	13.37	11.43	4.60
31,745	7.37	9.70	12.80	15.40	13.77	14.25	13.10	5.00
40,000	7.80	11.20	13.47	15.63	14.03	14.23	12.83	3.80
40,816	7.50	10.37	12.80	14.23	13.9	13.42	12.60	5.10
57,143	9.20	13.43	14.13	14.73	16.26	14.72	14.70	4.53
LSD	NS	NS	NS	NS	NS	NS	NS	NS
CV	19.56	26.204	25.33	23.31	20.59	17.24	NS	25.96

* = Means within the same column sharing the same letters are not significantly different at $p \leq 0.05$ according to Tukey's -test.
NS= non -significant difference at $p \leq 0.05$.

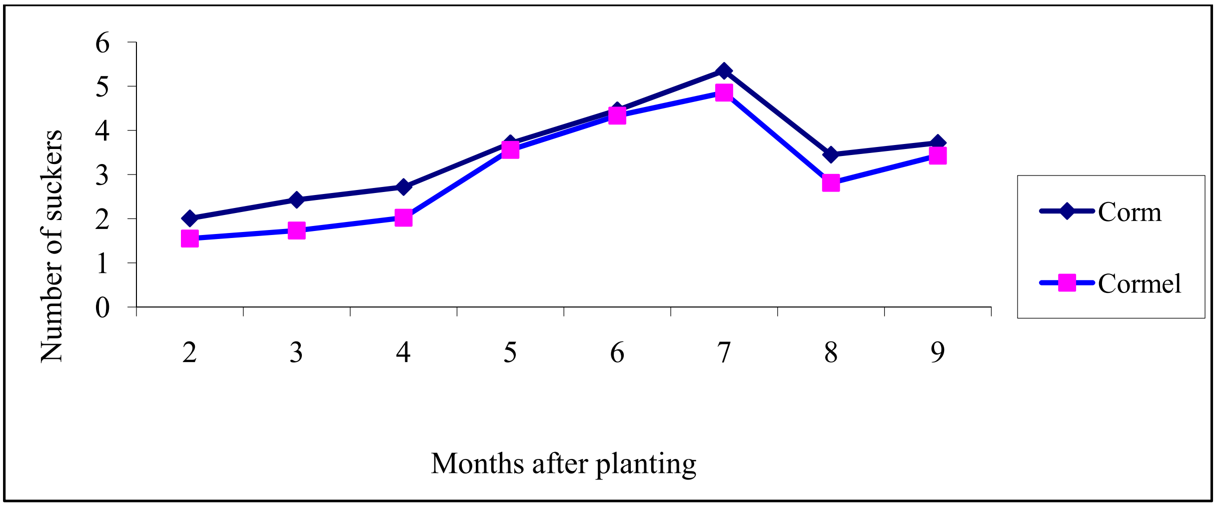

Figure 4 Mean shoot number per plant of taro plant from corm and cormel at different months after planting

Table 6. Mean shoot number per plant as affected by population density at different months after planting.

Treatment	Months after planting							
	2	3	4	5	6	7	8	9
Densities								
13,363	2.22	2.15ab	2.73	4.87a	5.08a	6.17a	3.33	4.83a
13,888	1.88	2.32ab	2.47	3.60ab	4.67ab	5.33ab	3.23	4.07ab
13,985	2.07	2.3ab	2.33	4.27ab	4.88ab	5.47ab	3.13	3.97ab
17,093	2.12	1.87ab	3.20	4.03a	4.22ab	5.10ab	3.63	3.83ab
17,857	1.95	2.10ab	2.67	3.97ab	4.68ab	5.37ab	3.43	3.80ab
18,181	1.52	1.27ab	2.37	3.63ab	5.05a	5.90a	3.10	3.60ab
21,977	1.87	1.77ab	2.07	4.27ab	3.97ab	4.37b	2.67	3.50ab
22,222	1.80	2.40ab	2.23	3.50ab	4.57ab	5.27ab	2.80	3.47ab
25,000	1.80	2.40ab	1.97	3.80ab	4.35ab	5.07ab	2.80	3.43ab
25,973	1.60	1.93ab	2.37	3.27ab	4.40ab	5.13ab	3.20	3.40ab
28,570	1.77	2.60a	2.30	3.40ab	4.28ab	5.23ab	3.10	3.23ab
30,769	1.50	2.00ab	1.80	2.93ab	3.67b	4.43b	2.63	2.87b
31,745	1.57	1.65ab	2.47	3.57ab	4.43ab	5.07ab	3.27	3.38ab
40,000	1.57	2.12ab	2.27	2.97ab	3.95ab	4.30b	3.03	2.70b
40,816	1.48	1.83ab	2.23	2.87ab	4.10ab	5.13ab	3.20	3.13b
57,143	1.77	2.57a	2.43	3.2ab	4.07ab	4.37b	3.53	3.47ab
LSD	NS	1.266	NS	1.399	1.230	1.420	NS	1.694
CV	25.06	29.51	28.62	27.66	13.57	13.50	19.32	22.99

* = Means within the same column sharing the same letters are not significantly different at p≤ 0.05 according to Tukey's –test NS= non significant difference at p≤ 0.05

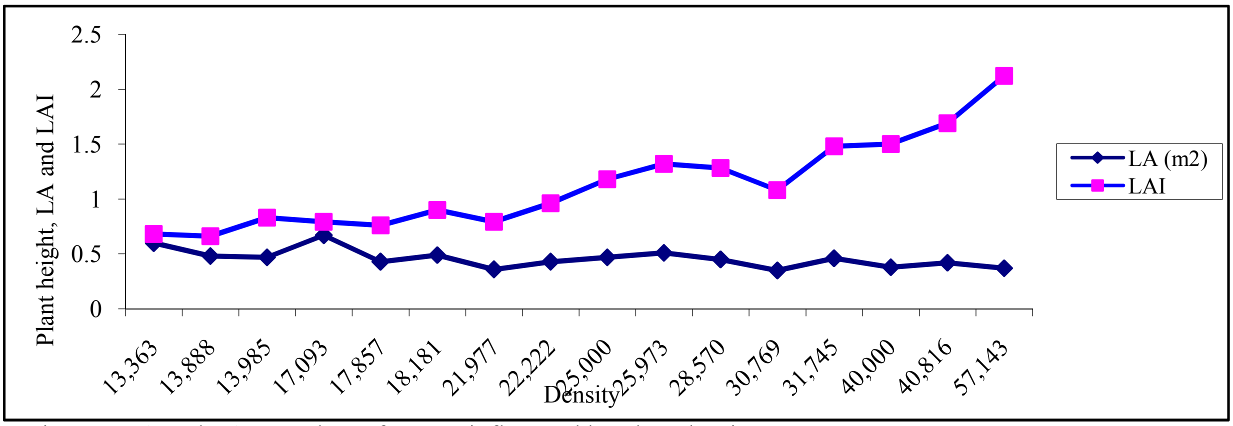

Figure 5 LA and LAI per plant of taro as influenced by plant density

Table 7. Date of emergence (DAP), leaf area (cm^2) and leaf area index per plant as affected by type of planting material at Areka, 2006

Treatments	50% emergence	Leaf area (cm^2)	Leaf area index
Corm	32.89b	4934.2a*	1.24
Cormel	35.58a	3995.7b	1.02
LSD 0.05	2.398	554.47	NS

*=Means within the same column sharing the same letters are not significantly different at p≤ 0.05 according to Tuckey's –test.
NS = non-significant effect at p≤ 0.05

Table 8. Mean number of corm, corm length (cm), corm diameter (cm), diameter length ratio (DLR), mean corm weight (g) and dry matter percentage as affected by type of planting material and population density at Areka, 2006

Treatments	Number of corm	Corm length	Corm diameter	DLR	Corm weight (g)	Dry matter %
Planting Material						
Corm	11.15	11.44	7.10	0.63	1283a	36.65a
Cormel	10.55	10.86	6.94	0.63	1028.73b	35.29b
LSD 0.05	NS	NS	NS	NS	75.86	1.32
Densities						
13,363	12.47ab	12.10	7.25a	0.62	1565a	35
13,888	11.57abc	12.20	7.25a	0.66	1582a	33.3
13,985	13.03a	10.87	7.06ab	0.66	1316.7abc	36.5
17,093	11.97abc	11.53	6.95ab	0.61	1118.3bcde	36.17
17,857	12.07abc	12.03	7.16a	0.60	1263.3abc	35.3
18,181	10.87abc	11.90	7.34a	0.62	1220abcd	33
21,977	10.57abc	11.37	7.16a	0.63	1121.7bcde	36
22,222	9.37b	11.17	6.88ab	0.62	1037.5bcde	36.67
25,000	9.03c	10.90	6.74ab	0.63	1402ab	36.17
25,973	11.43abc	11.00	7.28a	0.66	1097.7bcde	36.7
28,570	10.23abc	11.23	6.95ab	0.62	1128cde	35.17
30,769	8.77c	10.73	6.75ab	0.63	1015.7cde	35
31,745	11.03abc	10.57	6.61ab	0.63	1071.7bcde	36
40,000	9.03c	9.37	6.12b	0.67	870.de	39.5
40,816	9.27c	11.07	6.20b	0.57	833.7e	34.5
57,143	8.6c*	11.40	7.05ab	0.62	855.01de	35.83
LSD	3.371	NS	0.953	NS	383.49	NS
CV	15.41	13.658	6.669	13.21	16.07	9.086

* = Means within the same column sharing the same letters are not significantly different at p≤ 0.05 according to Tukey's –test. NS= non significant at 5% probability level

Table 9. Mean marketable, unmarketable and total yield (tha^{-1}) affected by type of planting material and population density at Areka, 2006

Treatments	Marketable Yield	Unmarketable yield	Total yield
Corm	21.90a*	5.88a	27.78a
Cormel	14.68b	4.298	18.98b
LSD 0.05	2.36	NS	2.85
Densities			
13,363	13.69defg	1.13b	14.72cde
13,888	12.95defg	1.16b	14.11cde
13,985	15.03cdefg	2.23b	17.25cde
17,093	11.89efg	1.92b	13.82cde
17,857	11.58efg	1.14b	12.72e
18,181	23.14bcde	4.199b	27.34bcd
21,977	15.03cdefg	2.71b	17.74cde
22,222	22.79bcdef	4.8b	27.63bc
25,000	7.19g	1.75b	8.94e
25,973	36.96a	12.89a	49.85a
28,570	16.57bcdefg	4.19b	20.61cde
30,769	10.87fg	2.21b	13.08de
31,745	26.79abc	13.68a	40.48ab
40,000	15.43cdefg	3.99b	19.42cde
40,816	28.03ab	11.47a	39.50ab
57,143	24.76bcd	12.19a	36.95ab
LSD	11.94	4.48	14.402
CV	32.17	36.52	29,68

* = Means within the same column sharing the same letters are not significantly different at p≤ 0.05 according to Tukey's- test. **NS=non significant at 5% probability level**

There was a highly significant (p≤ 0.001) effect of type of planting material by plant population density interaction on marketable and total yield (Figure 5).

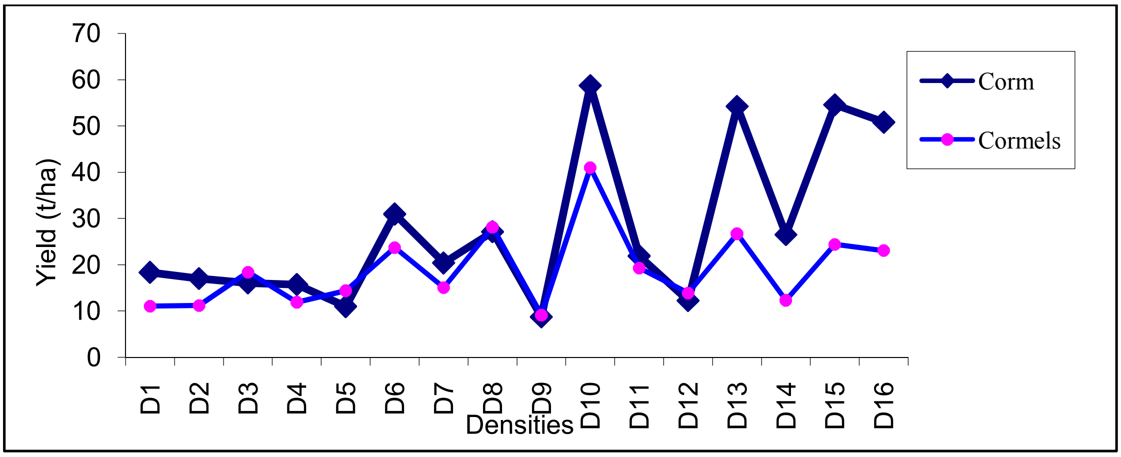

Figure 6 Interaction effect of type planting material and population density on total corm yield (tha^{-1}) of taro i.e. D1=13,363, D2=13,888, D3=13,985, D4=17,093, D5=17,857, D6=18,181, D7=21,977, D8=22,222, D9=25,000, D10=25,973, D11=28,570, D12=30,769, D13=31,745, D14=40,000, D15=40,818 and D16=51,143 plants/hectare.

Table 10. Associations of taro yield and yield components

	Le	Ph	Sho	Crl	Crd	Noc	Wtc	LA	LAI	Yield
Le	1	0.60***	0.71***	0.23*	-0.01ns	0.04ns	0.28***	0.42***	0.07ns	0.04ns
Ph		1	0.48***	0.21*	0.14ns	0.07ns	0.30***	0.39***	0.31**	0.47***
Sh			1	0.29**	0.03ns	0.21*	0.26**	0.35***	-0.04ns	-0.14ns
Crl				1	0.44***	0.1ns	0.31***	0.18ns	-0.05ns	-0.1ns
Crd					1	0.36***	0.47***	0.23ns	-0.13ns	0.07ns
Noc						1	0.54**	0.33***	-.022*	-0.15ns
Wtc							1	0.26***	-0.37***	-0.15ns
LA								1	0.39***	0.15ns
LAI									1	0.51***

** *Significant at p<0.001, * *p < 0.01, *p<0.05 probability level; ns = non significant at p< 0.05 probability level. Note:-Le = number of leaves per plant,Noc = number of corm per plant, Ph = plant height (cm) ,Wtc = weight of corm per plant, Sho = number of shoots per plant,LA = leaf area, Crl = corm length (cm),LAI = leaf area index, Crd = corm diameter (cm),Yield = yield in t/ha

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