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Yield and Yield Components of Onion (*Allium cepa* var. cepa) Cultivars as Influenced by Population Density at *Bir Sheleko*, North-Western Ethiopia

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Onions are among the most important vegetable crops produced in Ethiopia by both smallholder farmers and commercial growers for both local and export markets. However, information on plant population density that may provide optimum yield of bulbs for different cultivars is scanty. As a result, growers often use unspecified plant population densities for different cultivar, which could lead to sub-optimal bulb yields. Therefore, field experiment was conducted with the objective of determining the influence of plant population density on yield and yield components of two onion cultivars. The experiment was laid out as a randomized complete block design in a factorial arrangement in three replications. The treatments consisted of six plant population densities of 25, 33.33, 50, 66.67, 100 and 200 plants m-2 obtained from spacing of 40 cm x 10 cm, 30 cm x 10 cm, 20 cm x 10 cm, 30 cm x 5 cm, 20 cm x 5cm, and 10 cm x 5 cm, respectively and two popular onion cultivars (Adama Red and Bombay Red) in the study area. The data revealed significant differences in plant height and leaf length at maturity, bolting percentage, shoot fresh and dry weights, weight of marketable and total bulb yields, biological fresh and dry matter yields, average bulb fresh and dry weights, and neck diameter due to the main effects of cultivar and population density. Cultivars had significant main effects on harvest index, days to maturity, and biomass yield. Bombay Red was found to be superior to Adama Red in most parameters measured. Similarly, the main effects of plant population density had significant influences on the number of leaves per plant, number of marketable bulbs, and percent dry matter. The highest plant population density (200 plants m-2) resulted in the highest weights of marketable bulbs (47540 kg ha-1), total bulb yield (51137.2 kg ha-1), and the lowest bulb fresh weight (45.89 g). The interaction effects of cultivar and population density resulted in significant variation only in bolting percentage. However, plant height, leaf number per plant and leaf length at 30 days after transplanting, and total soluble solid content of onion bulbs were influenced by neither the main effects nor the interaction effects of cultivar and population density. In general, it could be deduced that plating onion at highest population density (200 plants m-2) could out-yield those of lower densities. However, optimum bulb size for fresh market use is generally contradictory whereas market in the study area accepts a bulb size of 20 g as marketable; the national recommendation for onion bulb size is 60 g. Thus, compromise decisions must be made for wider market and, hence, it could be recommended that preferred onion bulb size could be achieved by adopting 66.67 plants m-2 population density. Moreover, additional research on the cultivars for more seasons and under different agro-ecological conditions is suggested to draw a conclusive recommendation.

Keywords: Onion, Cultivars, Plant population, yield components, yield

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INTRODUCTION

Onion (*Allium cepa* L.) belongs to the genus *Allium* of the family *Alliaceae* [1]. Onion is by far the most important of the bulb crops cultivated commercially in nearly most parts of the world [2]. A region of especially high onions diversity stretches from Mediterranean basin to central Asia and Pakistan. The second, less pronounced centre of onions diversity occur in the western part of North America [3]. Alliums are typically plants of open, sunny, dry sites in arid climates. However, many species are also found in the steppes, dry mountain slopes, rocky or stony open sites, or summer dry, open, scrubby vegetation [1]. They are weakly competitive and, therefore, are not normally found in dense vegetation [4].

Onions contribute significant nutritional value to the human diet, have medicinal properties and primarily consumed for their unique flavor or for their ability to enhance the flavor of other foods [5]. They are used primarily as flavoring agents and their distinctive pungency, which is due to the presence of a volatile oil (allylpropyl disulphide). The mature bulb contains some starch, appreciable quantities of sugars, some protein, and vitamins A, B, and C [6]. It is also used as preservative and medicine [7].

Onion is growing in more than 130 countries in the world. Total world production in 2009 was estimated to 72.3 million tonnes and covering area of about 3.7 million hectares [8]. Accordingly, onion ranks third after potato and tomato, respectively, in area coverage among vegetable crops production in the world [9]. Based on the average production, the world's top producer of onion is China, contributing an average of 29.1%. The average world production is about 19.59 t ha^{-1} [8]. Tropical countries, having about 45% of the world's arable land and grow about 35% of the world's onions production [10].

In Ethiopia, onions (common onion and shallot) are the most important bulb crops produced by small farmers and commercial growers for both domestic market and export. These crops are produced for home consumption and for sale as a source of income to many farmers in many parts of the country [11]. The authors reported that the per capita consumption of these crops is estimated to be over 1.74 kg and 5.9 kg/year, respectively in rural and urban centre. Onion is cultivated throughout the country being cultivated under both irrigated as well as rain fed conditions in different agro- climatic regions [12]. The best growing altitude for onions under Ethiopian condition is between 700 and 1800 m above sea level [13].

The common onion, though a recent introduction, is rapidly getting popularity among consumers [14]. The land acreage under onion production, total production and national average yield in the year 2008/2009 was estimated to be about 15628.44 ha, 148854.89 tonnes and 9.53 t ha^{-1}, respectively, which is very low as compared to the world's average production of 19.59 t ha^{-1} [15]. Many diverse and complex abiotic, biotic and human factors have contributed to the existing low productivity of onion.

Plant population density and type of cultivars used are known to affect yield of onion. Onion production is mainly influenced by environmental factors, cultivars and cultural practices [16]. The author further indicated that bulb yield increases with plant density and that this positively correlates with percentage light interception by the crop leaf canopy. In addition, onion bulb yield increased asymptotically with increased plant density and the mean bulb size correspondingly declined [17].

The recommended spacing for improved onion production in Ethiopia is 10 cm x 20 cm x 40 cm spacing where 10 cm is the spacing between plants, 20 cm spacing between rows and 40 cm is the width of plant bed including irrigation water path used for irrigating the plant [18]. However, this recommendation is irrespective of onion cultivars and works only for furrow irrigation system. There is scanty of information on appropriate plant spacing for rain fed and sprinkler irrigation methods of onion production.

In *Bir Sheleko*, the onion production practice commonly uses sprinkler irrigation with single row method of planting. In the area, onion is produced for local market as a source of cash income. The cultivars commonly produced are "Adama Red", "Bombay Red" and "Red Creole". However, one of the major problems to its production is improper agronomic practice used by farmers. The use of appropriate agronomic management has an undoubted contribution in increasing crop yield. The optimum level of any agronomic practice such as plant population, planting date, harvesting date, and fertilizer application to the crop varies with environment, purpose of the crop production and cultivar [19]. Full package of information is required to optimize onion productivity [14]. Plant population density is one of these information that need to be optimized. Planting of onion at appropriate density is no exception. Proper spacing ensures optimum plant growth through adequate utilization of moisture, light, space and nutrients [20]. Planting of onion at optimum density gives the best economic return [21]. Hence, optimum planting density of onions should be determined through conducting experiments based on its production areas and the cultivar of interest.

Considering its importance, onion is one of the potential vegetable crops for both domestic consumption and export. So, it is imperative to increase its productivity through appropriate agronomic practices among which optimum plant population density is one of the determinants. Therefore, this study was conducted in order to identify an optimum planting density for different cultivars of onion for enhanced bulb yields based on the following objective: To determine the influence of population density on yield and yield components of two onion cultivars.

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted at *Lai Bir*, West Gojam zone of Amhara Regional State, which is located 400 km south-west of Addis Ababa and 170 km south-east of Bahir Dar, the regional capital. The area has an annual rainfall of 1031 mm, and average minimum and maximum temperatures of 10.7 and 28.7 ^{0}C, respectively. The site is situated at an altitude of 1670 meters above sea level, at 10 ^{0}N latitude and 37 ^{0}E longitudes. The weather data obtained during the growing period for total rainfall, and mean maximum and minimum temperatures were 21.68 mm, 31.34 ^{0}C and 13.95 ^{0}C, respectively. The highest rainfall amounts (15.50 and 4.52 mm) were recorded for the months of December and May, respectively (*Bir* farm metrological station).

The soil type is nitosol**.** The analytical results of the experimental soil indicated that the soil was heavy clay in texture, with slightly acidic pH (6.29), having an organic carbon content of 2.11%, total nitrogen of 0.11%, available phosphorus of 6 ppm, and exchangeable potassium value of 1.43 cmol kg^{-1} soil. Soil containing low organic carbon, total nitrogen, available phosphorus, but very high in exchangeable potassium [22]. The result indicated that texture, total nitrogen, organic carbon and available phosphorus were not sufficient for onion production while pH was found optimum. Exchangeable potassium was not a limiting factor for onion production [17].

The major crops grown in the area include maize, wheat, sorghum, soybean, haricot beans, onion, and hot pepper. Among these crops, onion and hot pepper are predominantly cultivated as irrigated crops while the others are rain fed crops. In the area, both surface and sprinkler irrigation methods are practiced, while the area under sprinkler irrigation method is also expanding.

Experimental Materials

Onion *(Allium cepa L.)* cultivars used for the experiment were “Adama Red” and “Bombay Red” obtained from Melkassa Agricultural Research Centre. Both cultivars were released in 1980, and adapted within altitude of 700-2000 m and having flat globe bulb shape. “Adama Red” has characteristics of erect leaf arrangement, dark red bulb skin colour and 110-130 maturity days. “Bombay Red” has medium leaf arrangement, light red bulb skin colour and 110-120 maturity days [23].

Treatments and experimental design

The treatments consisted of two onion cultivars and six plant population densities. The plant populations were obtained from spacing of 40 cm x 10 cm, 30 cm x 10 cm, 20 cm x 10 cm, 30 cm x 5 cm, 20 cm x 5cm, and 10 cm x 5 cm, that resulted in population densities of 250,000, 333,000, 500,000, 667,000, 1,000,000 and 2,000,000 plants ha^{-1}, respectively. The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times. Thus, there were 12 treatment combinations in triplicates. The treatments were randomly allotted to each plot.

The size of each experimental plot was 2 m long and 1.5 m wide. The blocks were separated by a space of 1.5 m and the plots were separated by a distance of 1 m.

Cultural Practices

The nursery site used for raising seedlings was ploughed and harrowed well to a fine tilth using a tractor prior to preparation of seed-beds. Then, manual labour was used to make the nursery beds ready for sowing. The size of the bed was 1m wide and 5 m long. Twenty-three grams of phosphorus was applied per bed in the form of P_2O_5 before sowing. Seeds were drilled at the depth of 2 to 3 cm on beds. Immediately after sowing, all seedbeds were mulched uniformly, which was followed by immediate watering using a watering can. Nitrogen in the form of urea (46**%** N) was added two times at the rate of 43.5 grams per bed. Two weeding and two spraying of Indofil M-45 (Mancozeb) at the rate of 2 gram per litter water were performed in the nurseries to control thrips.

The experimental field was ploughed and harrowed using a disc plough mounted tractor and manual labour was used to layout the field and make the plots ready for planting. Seedlings with 4 to 5 green true leaves (45 days after sowing) were transplanted to the experimental field plots. Only vigorous and healthy seedlings of uniform size were transplanted.

Fertilizer was supplied according to the recommendation of [23]. Nitrogen was applied at the rate of 87 kg N ha^{-1} and phosphorus was applied at the rate of 46 kg P_2O_5 ha^{-1}. The sources of the fertilizers were Urea (46% N) and DAP (18% N and 46% P_2O_5). All the required amount of DAP was applied in band just before planting at the depth of 10 cm below the soil level of positioning the roots of the seedlings. Urea was applied twice, where 50% of the total amount of the fertilizer was applied at transplanting and the remaining 50% was applied at the active stage of vegetative growth of the plants about six weeks after transplanting. Onion plants were treated with Dimethoate (40% EC) and Diazol (60% *a.i*) at the rate of 1.5 litre active ingredient (*a.i*) per 200 litre water per hectare for controlling thrips. Furthermore, other necessary cultural practices such as weeding and watering were carried out accordingly on all plots using sprinkler irrigation system.

DATA COLLECTION

Days to maturity, bolting percentage and yield data were recorded from all plants in the middle rows leaving aside plants from the border rows and those at both edges of each row while other growth and bulb characters were collected from 15 randomly taken plants from the central rows.

Data Collected and Measurements

Plant height (cm): Measured from the ground level to the top of a matured plant at 30 days after transplanting (DAT) and at maturity.
Number of leaves per plant: The total number of leaves was counted and recorded 30 DAT and at maturity.
Leaf length (cm): The average length of leaf blades of the plants measured at 30 DAT and at maturity and expressed in centimetres
Shoot fresh weight (kg): The above ground biomass of the plant was harvested by cutting at the crown of the plant at harvest.
Shoot dry weight (kg): The shoot fresh mass was oven-dried at the temperature of 65 ^{0}C for 72 hours and its dry matter yield was determined and expressed in kilograms.
Days to maturity: The total number of days from emergence until 70 percent of the plants has attained physiological maturity.
Total bulb yield (kg): The sum of marketable and unmarketable (culls) bulb yields and was expressed in kilograms.
Number and weight (kg) of marketable bulbs: Recorded as the number and weight of healthy and marketable bulbs at harvest.
Number and weight (kg) of unmarketable bulbs (culls): Determined through subjective evaluation and recorded as the weight and number of diseased, decayed, insect attacked and abnormal bulbs including multiple bulbs, thick necked bulbs, too small bulbs (below 20 g weight) *etc* at harvest.
Bolting percentage (%): Plants showing flower scapes were counted and calculated as the ratio of bolters per total plants in the plot.
Biological fresh matter yield (kg): The total yield of the plant including bulbs, shoots, and roots after curing for one week.
Biological dry matter yield (kg): This was determined by oven-drying the biological fresh matter yield at the temperature of 65 ^{0}C for 72 hours and weighing using a scale balance.
Neck diameter (cm): The average neck width was measured using veneer calliper and expressed in centimetre after harvest.
Bulb diameter (cm): the average radial width was measured by using veneer calliper and expressed in centimetre after harvest.
Bulb fresh weight (g): The average fresh weights of fifteen mature bulbs were measured using digital sensitive balance after harvesting and expressed in grams.
Bulb dry weight (g): Bulb fresh weight was recorded, and then the bulbs were chopped to small pieces and oven dried at 70 ^{0}C until to a constant weight. After the weight was measured using digital balance, percent dry matter was calculated using the formula:

DW (%) = {[DW + CW]-CW}/ {[FW+CW]-CW**} X 100**
Where: DW = dry weight
CW = container weight
FW = fresh weight

Harvest index: This was recorded as the ratio of bulb dry yield to the biological dry yield and expressed in percentage.
Total soluble solid (TSS): The TSS was determined from fifteen randomly selected bulbs using the procedures [24]. Aliquot juice was extracted using a juice extractor and 50 ml of the slurry centrifuged for 15 minutes. The TSS was determined by hand refractometer (ATAGO TC-1E) with a range of 0 to 32° Brix and resolutions of 0.2° Brix by placing 1 to 2 drops of clear juice on the prism, washed with distilled water and dried with tissue paper before use. The refractometer was standardized against distilled water (0% TSS). Amount of total soluble solids present in the bulb expressed in percentage.

Soil Sampling and Analysis

Pre-planting soil samples were taken randomly in a zigzag pattern from the entire experimental plots at the depth of 0-30 cm. Ten soil cores were taken by an auger from the whole experimental field and combined to a composited sample. The soil was broken in to small crumbs and thoroughly mixed. From this mixture, a sample weighing one kg was filled in to a plastic bag. This was analysed in triplicates.

The soil was air dried and sieved through a 2 mm sieve. Then, soil pH was determined in a 1: 2.5 soil water ratio potentiometrically using a glass-calomel combination electrode [25]. Texture of the soil was determined by sedimentation method.

The soil samples were analyzed for total nitrogen, exchangeable potassium, and available phosphorous and organic carbon. Total nitrogen of the soil was determined by the micro Kjeldhal procedure. The formula used earlier [26] determined organic carbon. Available phosphorous content of the soil was determined by extracting the soil with 0.5 M $NaHCO_3$ solution [27]. Phosphorus in the extracts was determined with atomic absorption spectrophotometer calorimetrically according to the molybdenum blue colour method [28]. Exchangeable potassium was determined using a flame photometer after extracting the soil with 0.5 N ammonium-acetate.

STATISTICAL ANALYSIS

Data were subjected to analysis of variance using the General Linear Model of SAS Statistical Software package [29]. Pearson Correlation coefficients were determined for parameters by the same software. Means that differed significantly were separated using the LSD procedure at 5% level of significance.

RESULTS AND DISCUSSION

Effects of Cultivars and Plant Population Density on Growth Parameters

Plant height

The main effects of cultivar, plant population density and their interaction did not indicate any significant effect on plant height 30 days after transplanting (DAT). However, both cultivar and plant population density had significant ($P < 0.05$) and highly significant ($P < 0.01$) main effects on plant height at maturity of the crop plant, respectively. While their interaction effect was not significant (Table 1).

At maturity time, the mean plant height of “Adama Red” cultivar significantly exceeded that of “Bombay Red” cultivar by about 11% (Table 1). The variation in plant height could be attributed to genetic differences between the cultivars and their reaction to the prevailing environmental conditions. Similar findings were also reported [30, 31].

As plant population density of the onion increased from 25 plants m^{-2} to 50 plants m^{-2}, plant heights at maturity remained statistically non-significant. However, as the plant population density increased to 66.67 plants m^{-2}, 100 plants m^{-2}, and 200 plants m^{-2}, plant heights diminished significantly ($P < 0.01$). However, heights of plants grown at these three higher population densities were in statistical parity (Table 1).

Plants grown at the population density of 25 plants m^{-2} were the tallest, and in statistical parity with the heights of plants grown at the population density of 33.33 and 50.00 plants m^{-2}. The lowest plant height was obtained at 200 plants m^{-2}, which was statistically the same with plant heights obtained at the population density of 66.67 plants m^{-2} and 100 plants m^{-2}.

In general, the height of onion plants decreased by about 32% with increase of plant population density from 25 plants m^{-2} to 200 plants m^{-2}. As a whole, plant height decreased with increasing plant population densities, but the decrease was relatively more pronounced for the Adama Red cultivar than for the Bombay Red cultivar.

The nature of growth of the onion plant is erect and open canopy, which would minimize competition for light between neighbouring plants. Therefore, this nature of the crop apparently avoided etiolated growth during the study. Hence, the decrease in plant height as population density increased may be attributed to the inevitable increases in competition among the plants for other growth factors such as moisture and nutrients.

The result obtained on plant height in this study is corroborated by earlier study [32, 33, 34]. Similarly, a study on garlic revealed that plant height, diameter, bulb size and number of cloves were greater with cloves planted at the widest spacing [35].

Number of leaves per plant

Cultivar had no significant main effect on the number of leaves per plant 30 days after transplanting and at maturity. Population density had no significant main effect on the number of leaves per plant 30 DAT, whereas there was highly significant ($P < 0.01$) main effect on number of leaves per plant at maturity. Cultivar and population density had no significant interaction effect on this plant parameter (Table 1).

When plant population density was increased from 25 plants m^{-2} up to 50 plants m^{-2}, the number of leaves produced per plant remained statistically the same at maturity. However, when plant population density was increased from 25 plants m^{-2} to 66.67, 100, and 200 plants m^{-2}, the number of leaves produced per plant was significantly ($P < 0.01$) reduced by about 17, 18, and 40%, respectively. However, at these three higher plant population densities, the numbers of leaves produced per plant were in statistical parity (Table 1). The highest number of leaves per plant was produced at plant population densities of 25, 33.33 and 50 plants m^{-2}.

The increase in the number of leaves produced per plant in response to decreasing plant population density, could be partly ascribed to less concurrence among the widely spaced plants for growth factors such as light, moisture and nutrients. This may have resulted in higher leaf number per plant. This result is in agreement with earlier study who found more number of leaves per plant (12) of onion at minimum plant population density (20 plants m^{-2}) which decreased with increase in plant population [36].

This observation is also in conformity with the work of other author who reported that widely spaced garlic plants tend to grow more vegetative and bear more leaves per plant [37]. It was possible that the plants at high population density might have experienced serious competition for growth factors to the extent that can

Table 1. Main effects of cultivar and plant population density on onion plant height 30 DAT and at maturity, leaf number per plant 30 DAT and at maturity, leaf length 30 DAT and at maturity.

Treatment	Growth Parameters					
	Plant height 30 DAT (cm)	Plant height at maturity (cm)	Leaf no. per plant 30 DAT	Leaf no. per plant at maturity	Leaf length 30 DAT (cm)	Leaf length at maturity (cm)
Cultivar						
Adama Red	23.00	62.25a	4.79	15.87	17.05	41.01a
Bombay Red	22.38	56.04b	4.86	16.04	15.77	36.81b
$LSD_{(5\%)}$	ns	5.09	ns	ns	ns	3.53
Population density (plants m^{-2}**)**						
25	24.82	67.06a	5.02	18.17a	17.60	43.15a
33.33	23.67	63.94ab	4.81	17.52a	16.78	41.55a
50	22.90	61.93abc	4.72	16.04ab	16.62	39.69a
66.67	22.74	56.95bcd	4.82	15.57b	16.38	37.86ab
100	21.48	54.00cd	4.91	15.43b	16.29	37.39ab
200	20.54	50.97d	4.69	13.01c	14.79	33.83b
$LSD_{(5\%)}$	ns	8.82	ns	2.31	ns	6.11
CV (%)	12.69	12.45	10.61	12.08	13.08	13.11

ns = non-significant at 0.05 probability level. Means sharing the same letter within a column are not significant different at 5% level of significance.

depress growth or alternatively the plants were not opportune to have a micro-environment that is equally fertile and moist compared to those treatments with lower population density.

Leaf length

Analysis of the data on leaf length revealed that both cultivar and plant population density had no significant main effects on leaf length 30 days after transplanting (30 DAT), while this was significant ($P < 0.05$) main effects on leaf length at maturity. The interaction effect of the two factors was non significant on this plant parameter (Table 1).

"Adama Red" was found significantly longer than "Bombay Red" in average leaf length at maturity, which was about 11% (Table 1). The difference in leaf length of the cultivars could be attributed to mere differences in the genetic constitution of the plants. Similar results were also reported by other authors for variation in leaf length among cultivars [38].

The effect of plant population densities of 25, 33.33, 50, 66.67, and 100 plants m^{-2}, plants on leaf length at maturity was produced statistically the same. However, leaf length was significantly ($P < 0.05$) reduced when the population density increased from 25, 33.33, and 50 plants m^{-2} to 66.67, 100 and 200 plants m^{-2} with a significant reduction at 200 plants m^{-2}. The leaf length under the population density of 200 plants m-2 was lower by about 28%, 23% and 17% than under population density of 25, 33.33 and 50 plants m^{-2}, respectively. However, the mean leaf length of plants grown at the population densities of 66.67 and 100 plants m^{-2} remained in statistical parity with that of plants grown at density level of 200 plants m^{-2} (Table 1).

The data generally revealed that an increasing plant population density decreased leaf length, which could be attributed to increased competition for growth factors (nutrients and moisture). Other workers [39, 34, 35, 40] reported similar results.

Bolting percentage

Analysis of variance revealed that both cultivar and plant population density had highly significant ($P < 0.01$) effect on bolting percentage of onion. However, the result also showed that the two factors interacted to influence this plant parameter (Table 1).

The data generally showed that increasing plant population across both cultivars increased bolting percentages. “Bombay Red” was evidently more susceptible to bolting than “Adama Red” when plant density was increased. The highest bolting percentage was recorded for “Bombay Red” cultivar at the highest population density (200 plants m^{-2}). This was closely followed by the bolting percentages of the same cultivar at 100, 66.67, and 50 plants m^{-2}. The bolting percentage of the “Bombay Red” cultivar at the population density of 33.33 plants m^{-2} and those of the “Adama Red” cultivar at the population densities of 66.67, 100, and 200 plants m^{-2} were in statistical parity. For the “Adama Red” cultivar, no bolting occurred at the lower population densities of 25, 33.33, and 50 plants m^{-2}. Premature bolting increased as plant population increases. This could be attributed to relative increase of competition for nutrients and leaf area index when plant population density increases, which enhance growth and development. Similarly, other authors that control of bolting whilst maintaining yield requires high levels of soil nitrogen availability during growth and a leaf area index less than 3.5 [41]. (Figure1)

Shoot fresh and dry weights

Cultivar had no significant main effect on onion shoot fresh and dry weight. On the other hand, plant population density had a highly significant ($P < 0.01$) main effect on these plant parameters. The two factors did not interact to influence onion shoot fresh and dry weights (Table 2).

Both fresh and dry shoot weights of onion showed similar trend and increased as the plant population density increased. Both shoot fresh and dry weights remained relatively small and statistically the same as the population density was increased from 25 plants m^{-2} to 33.33, and 50 plants m^{-2}. However, the increase of the two parameters was highly significant ($P < 0.01$) when the plant population density was increased from 25 plants m^{-2} to 66.67, 100 and 200 plants m^{-2}. The increase in shoot fresh weight as the population density was increased from 25 plants m^{-2} to 66.67, 100 and 200 plants m^{-2} amounted to 47, 106, and 269%, respectively.

The increase in the shoot dry weight was 53, 111, and 193% in the same order. The highest values of shoot fresh weight were recorded for the most densely populated plots (200 plants m^{-2}) whereas the lowest values were obtained from the most sparsely populated plots (25 plants m^{-2}) (Table 2). The highest shoot fresh and dry weights observed due to high plant population density could be attributed to early canopy development, which may have consistently increased light interception and photosynthesis. In agreement with the present findings, [42], observed increased dry matter in vegetative parts, as plant density increased. Similarly, the total above ground biomass production of cabbage reduced by about 28% as spacing increased from 45 cm x 20 to 45 cm x 60 [43].

Biological fresh matter yield

Cultivar and population density indicated highly significant ($P < 0.01$) main effects on biological fresh matter yield while their interaction effect was non-significant (Table 2).

“Bombay Red” produced about 62% more biological fresh matter yield than “Adama Red” (Table 3). The probable reason for such variation between the cultivars could be attributed to differences in plant architecture and the rate at which the canopy closes and efficiency of the cultivar in using radiation for photo assimilation. This, in turn, may be a genetic characteristic. Consistent with this suggestion, authors observed variation in radiation use efficiency within species of cowpea [44]. The present result is in agreement with the results obtained by earlier study [45].

Biological fresh matter yield significantly ($P < 0.01$) increased with the increase in plant population density (Table 3). The highest fresh matter biological yield was obtained at 200 plants m^{-2} population density, which was significantly different from that obtained under plants grown at population density of 100 plants m^{-2}. The lowest biological fresh matter yield was recorded from plants grown at the most sparsely populated plots (25 plants m^{-2}). The fresh matter biological yield obtained from plants grown at density level of 33.33 plants m^{-2} was in statistical parity with that of plant population density level of 25 plants m^{-2}.

The biological fresh matter yield scored at 50, 66.67 and 100 plants m^{-2} population densities were lower than that scored under the population density of 200 plants m^{-2} by about 165, 90 and 60%, respectively.

The enhancement of biological fresh matter yield in densely populated plant could be attributed to the higher leaf area or avoidance of wastage in light energy due to coverage by high plant population that could increase photosynthetic rate per unit area resulting in more assimilate stored in above ground plant part and in bulbs. Corn LAI and light interception were increased linearly as planting density increased from 7 to 13 plants m^{-2}. Furthermore, these authors showed that the highest biological yield was produced in the highest plant density, while the least plant density produced the lowest biological yield. [46].

Similarly, biological yield of soybean increased by 30.4% with increase in plant density from 20 to 60 plants m^{-2} [47]. In addition, high population density was found to be beneficial to biomass production in soybean [48]. Highest biomass yield of carrot at spacing of 2 cm

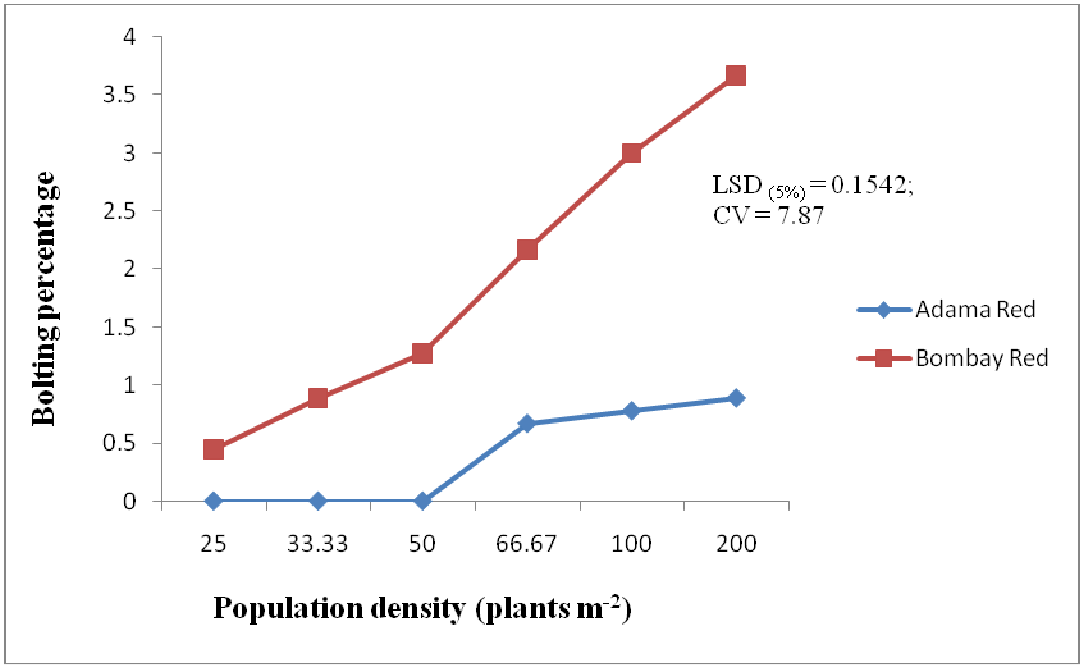

Figure 1. Interaction effects of cultivar and population density on bolting percentage of onion.

Table 2. Main effects of cultivar and plant population density on onion shoot fresh and dry weights.

Treatment	Growth Parameters	
	Shoot fresh weight (kg ha^{-1})	Shoot dry weight (kg ha^{-1})
Cultivar		
Adama Red	9562.90	1150.54
Bombay Red	8875.70	1047.27
LSD $_{(5\%)}$	1167.30	119.93
Population density (plants m^{-2}**)**		
25	5277.8d	669.20d
33.33	5225.2d	681.90d
50	6703.9cd	845.30cd
66.67	7766.7c	1023.30c
100	10860.0b	1412.30b
200	19482.2a	1961.30a
LSD $_{(5\%)}$	2021.7	207.72
CV (%)	18.32	15.79

ns = non-significant at 0.05 probability level. Means sharing the same letter within a column are not significant different at 5% level of significance.

whereas the lowest biomass yield was obtained at 10 cm spacing [49].

Biological dry matter yield

Both cultivar and population density revealed highly

Table 3. Main effects of cultivar and plant population density on biological fresh and dry matter yields.

Treatment	Growth parameters	
	Biological fresh matter yield ($kg\ ha^{-1}$)	Biological dry matter yield ($kg\ ha^{-1}$)
Cultivar		
Adama Red	29435b	3866.2b
Bombay Red	47713a	4748.9a
$LSD_{(5\%)}$	4176.7	630.7
Population density (plants m^{-2}**)**		
25	15273e	1700.5e
33.33	19757e	2285.4de
50	29289d	3085.6cd
66.67	40859c	3898.2c
100	48581b	5543.1b
200	77685a	9332.4a
$LSD_{(5\%)}$	7234.3	1092.4
CV (%)	15.66	21.18

Means followed by the same letter within a column are non-significantly different at 5% level.

significant ($P < 0.01$) main effect on biological dry matter yield of the crop plant (Table 2). Nevertheless, their interaction effect was not significant.

"Bombay Red" produced significantly more biological dry matter yield (23%) than Adama Red. The difference in biological dry matter yield between cultivars could be due to their genetic difference in response to growing environment. Likewise, earlier study indicated that onion genotype usually shows its best yield only in a specific environment [50].

Biological dry matter yield significantly increased with the increase in plant population density (Table 3). Among the plant population densities evaluated, the highest biological dry matter yield was obtained from the most densely populated plots (200 plants m^{-2}), and the lowest was from the most sparsely populated plots (25 plants m^{-2}). The result of 25 plants m^{-2} density level was in statistical parity with the biological dry matter yield obtained from plots populated at 33.33 plants m^{-2}. As population density increased from 25 plants m^{-2} to 200 plants m^{-2} 449% biological dry matter yield increment was recorded.

The result observed in this study could be due to the fact that higher plant population densities produce relatively higher vegetative growth (leaves), which intercept greater amounts of solar radiation and consequently produced high dry matter [51]. This was in agreement with earlier findings [52], who also reported increasing dry matter with increasing level of population density.

Effects of Cultivars and Plant Population Density on Yield Parameters

Number and weight of marketable bulbs

Cultivar had no significant effect on the number of marketable bulb production. In contrast, it had significant ($P<0.05$) main effect on weight of the marketable bulbs. However, population density had highly significant ($P < 0.01$) main effects on both of these parameters. Cultivar and population density interaction did not influence both the number and weight of marketable yields (Table 4).

The result revealed that the weight of marketable bulbs of the "Bombay Red" was 16% higher than that of "Adama Red". The present finding is consistent with other [53], who reported significant differences between onion cultivars for marketable bulb per plot. Garlic genotype "Bhote Lasun" produced the highest marketable yield (19.5 $t\ ha^{-1}$) than the local (11.4 $t\ ha^{-1}$) [54].

The effect of plant population density on the number and weight of marketable bulbs was found to be highly significant ($P < 0.01$) (Table 4). The number of marketable bulbs increased progressively with increased plant population density. Thus, significantly higher number of marketable bulbs was produced at each higher plant population density than the lower plant population densities. The highest number of marketable bulbs was

Table 4. Main effects of cultivar and plant population density on onion number and weight of marketable bulbs, number and weight of unmarketable bulbs and total bulb yield.

Treatment	Yield Parameters: Number of marketable bulbs	Weight of marketable bulbs (kg ha^{-1})	Number of unmarketable bulbs	Weight of unmarketable Bulbs (kg ha^{-1})	Total bulb yield (kg ha^{-1})
Cultivar					
Adama Red	755061	26003b	40936	1516.52	27519.52b
Bombay Red	754611	30089a	37562	1528.36	31617.36a
LSD $_{(5\%)}$	ns	3569.4	ns	ns	3593.2
Population density (plants m^{-2}**)**					
25	239204f	9807e	10796e	1166.3b	10973.3 e
33.33	317106e	17693d	16194de	1051.6b	17219.6d
50	479082d	25450c	20918cd	1088.1b	26538.1 c
66.67	639709c	31334bc	26991c	1107.3b	32441.3bc
100	964238b	36453 b	35762b	1124.2b	37577.2b
200	1875169a	47540a	124831a	3597.2a	51137.2 a
LSD $_{(5\%)}$	66567	6182.4	7185.3	299.74	6223.7
CV (%)	7.37	18.41	15.29	16.44	17.73

ns = non-significant at 0.05 probability level. Means followed with the same letter within a column are not significant different at 5% level of significance.

attained due to plant population density level of 200 plants m^{-2}, and the lowest was recorded at the density level of 25 plants m^{-2}. The number of marketable bulbs obtained at 200 plants m^{-2} population density exceeded that produced at 100, 66.67, 50, 33.33 and 25 plants m^{-2} by about 96, 194, 292, 497, and 685%, respectively. The marked differences observed among plant population densities in the number of marketable bulbs produced are in accordance with earlier findings of other researchers. The number of rows per bed increased or in-row spacing decreased, marketable onion bulb increased linearly while mean bulb weight decreased [55]. Similar result also reported that percent marketable bulbs increased as plant population density increased [56]. The result of the present study is also in agreement with other study [57], who obtained maximum number of marketable cabbage head from plots with the highest plant population densities.

Similarly, marketable bulb yield increased significantly (P < 0.01) when plant population density was increased from 25 plants m^{-2} to 200 plants m^{-2}. The highest weight of marketable bulbs was recorded under plant population density level of 200 plants m^{-2} while the lowest was scored under the density of 25 plants m^{-2} (Table 4). The weight of marketable bulbs obtained at 200 plants m^{-2} population density significantly exceeded that of 100, 66.67, 50, 33.33 and 25 plants m^{-2} by about 30, 52, 87, 169, and 385%, respectively. However, the weights obtained at the population densities of 50 and 66.67 plants m^{-2} and 66.67 and 100 plants m^{-2} were not statistically different.

Similarly, number and yield of marketable onion bulbs was higher at higher plant densities [58]. Similarly, yields of marketable bulbs amounting to 24, 29 and 39 t ha^{-1} as population densities increases to 22, 33 and 67 plants m^{-2}, respectively [59]. Other study also found that the marketable yield of carrot (*Daucus carota* L.) at 2 cm spacing significantly exceeded those at 6, 8, and 10 cm by about 30, 32, and 57%, respectively [49]. The results of this study are also consistent with that of [43] who demonstrated increased marketable yield of head cabbage with narrower plant spacing.

Number and weight of unmarketable bulbs

There was no significant different between the cultivar on the number and weight of unmarketable bulbs. In contrast, population density had highly significant ($P < 0.01$) main effect on these parameters of the plant. Nevertheless, the interaction effect of cultivar and plant population density did not significantly affect these parameters (Table 4). This seems to indicate that the influence of population density on these characters was independent of the variation in cultivars.

The number and weight of unmarketable bulbs increased significantly ($P < 0.01$) due to increasing plant population density (Table 4). The number of unmarketable bulbs obtained at 200 plants m^{-2} population density significantly exceeded those obtained at population densities of 100, 66.67, 50, 33.3 and 25 plants m^{-2} by about 249, 362, 497, 671, and 1056%, respectively. The number of unmarketable bulbs obtained at the plant population densities of 25 and 33.33 plants m^{-2} was the lowest, and statistically the same. The second lowest numbers of unmarketable bulbs were obtained from the plant population densities of 50 and 66.67 plants m^{-2}, and were also in statistical parity.

In general, high population density decreased mean bulb sizes, increased bolting percentages, produced poorer quality bulb, and thus increased the proportion of unmarketable bulbs (Table 5).

Similarly, the highest weight of unmarketable bulbs was recorded at plant population density of 200 plants m^{-2}. Weight of unmarketable onion bulbs was increased by about 208% when plant population density was increased from 25 plants m^{-2} to 200 plants m^{-2}. The values at the population densities of 25, 33.33, 50, 66.67 and 100 plants m^{-2} were found to be statistically similar. These results are in agreement with those of [60] who found that weight of cull bulbs (unmarketable) increased with increase in planting density. The author indicated that planting density of 20 plants m^{-2} produced the maximum cull bulbs followed by cull bulbs at medium planting density of 15 plants m^{-2}, while minimum weight of cull bulbs was recorded at lower planting density of 10 plants m^{-2}. Higher proportion of number and weight of unmarketable bulbs obtained at higher plant population densities could be attributed to pre mature bolting and increment in the number of very small (cull bulbs) resulted from stiff competition for growth factors. Previous reports also indicated that onions grown at high densities result in large proportion of smaller and irregular shaped bulbs [32]. Significantly higher unmarketable cabbage heads at the highest population density were also reported by earlier study [43].

Total bulb yield

Cultivar and population density had significant ($P < 0.05$) and highly significant ($P < 0.01$) effects, respectively on total bulb yield. However, the interaction effects of cultivar and population density was found to be non-significant (Table 4).

"Bombay Red" produced higher total bulb yield than "Adama Red", exceeding by about 17% (Table 4). Difference in productivity among cultivars could be ascribed to genetic differences. Corroborating this suggestion, several workers also reported the variation in bulb yield among different cultivars [30, 39, 45, 40]. The difference in bulb yield of onion in many countries indicate the dependence of this mainly on variation in genotypes, climate, cultural practices and their interactions [17]. Thus, each land race is adapted to a specific climatic condition and many quantitative and qualitative characters in onion have a clear genetic basis that can be changed by onion breeders in order to get optimum yield.

Total bulb yield increased significantly ($P < 0.01$) with increased plant population density (Table 4). The total bulb yield obtained at 200 plants m^{-2} population density level markedly increased by about 36, 58, 93, 173, and 366%, respectively compared to the bulb yields obtained at 100, 66.67, 50, 33.3 and 25 plants m^{-2}. The total bulb yield recorded at 25 plants m^{-2} density level was the lowest, followed by the yield obtained at 33.33 plants m^{-2}. The positive increase in total bulb yield at higher plant population density could be ascribed to an increased in plant population per unit land area. However, resulted in lower yield per plant due to reduced size of individual bulbs emerged from increased competition growth factors. Therefore, this study confirms that the total yield per unit area depends not only on the performance of individual plants but also the number of plants per unit area.

In addition, the yield difference between the highest and the lowest plant population densities could be due to increased leaf area index at high plant population density, which in turn improved radiation interception. Similar results were also reported that increasing plant population density proportionally increases yield per unit area [30, 34, 40]. Similar results were reported on onion [34]. Likewise, carrot found 50% yield increment at intra-row spacing of 2 cm over the least dense populated plants (10 cm) [49].

However, in the highest plant population density, bulb size may be too small for marketing so that consumers may not accept it for salad or condiment. Nevertheless, it has been reported that there are niche markets for bulb sizes in Ethiopia where small-sized bulbs may be preferred to large-sized bulbs by specific sections of the society, whereas large-sized bulbs are demanded by others. Peasant households usually like small-sized bulbs because a single bulb may be enough for preparation of one-time stew ‘wot’. Thus, there may not be the need to store partitioned large-sized bulbs that would be used for more than one time. In such households, cut bulbs cannot be stored due to lack of refrigerating facilities. However, for hotels and other households in urban centres, large-sized bulbs are preferred because of high consumption and availability of refrigerating facility.

Effects of Cultivars and Plant population density on Onion Yield Components

Bulb fresh weight

The study revealed that the main effects of both cultivar and population density had highly significantly ($P < 0.01$) affected the average fresh bulb weight, while their interaction effect was not significant on this parameter (Table 3).

Average bulb fresh weight of “Bombay Red” significantly exceeded the average bulb fresh weight of “Adama Red” by about 34% (Table 5). This may be due to genetic differences between cultivars in photosynthesis and assimilate partitioning. This result is in agreement with [40] who reported that bulb fresh weight difference between onion cultivars.

The data revealed that the average bulb fresh weight was significantly ($P < 0.01$) and consistently decreased with increasing plant population density. Plants grown under lowest plant population density produced significantly large-sized bulbs than those grown at higher density levels. Consequently, increasing plant population density from 25 plants m^{-2} to 200 plants m^{-2} decreased average bulb fresh weight by about 65%. However, the individual bulbs produced at density level of 200 plants m^{-2} were least heavy (Table 5). Compared to the average bulb fresh weight of plants grown at the population density of 25 plants m^{-2}, the average bulb fresh weights of plants grown at the population densities of 66.67, 100, and 200 plants m^{-2} significantly decreased by about 28, 45, and 65%.

The result also indicated that wider spacing had linearly increasing effect on the performance of individual plants. This could be ascribed to plants grown with wider spacing have more area of land around them to draw sufficient moisture and nutrients and intercept more solar radiation for better photosynthetic process and performed better than plants grown in closer spacing and exposed to competition. At low population density, where competition for growth factors is low, mean bulb yield per plant was higher as compared to those under higher plant population density [61]. However, as plant population increased, competition appeared to be more important and leads to lower bulb weight.

The present finding is supported by other researchers [56, 34, 40]. According to the authors, an increase in population density decreases mean weight of bulbs of onion while yield per unit area increases. Other author evaluated three planting densities of onion also reported the production of more bulbs at highest density (80 plants m^{-2}) while the weight of their individual bulbs was less than bulbs grown at lower densities (26.6 or 40 plants m^{-2}) [62]. Similarly, the larger super colossal garlic cloves were recorded at less dense plantings, while yield of smaller cloves (40-45 mm) was increased at a higher density [63]. Furthermore, yield per plant decreases gradually with increasing plant population per unit area [42].

In other vegetable crop, cabbage, effects of plant spacing and varieties on individual head weight of cabbage as a single factor were different ($P < 0.01$) [43]. His further report said that increasing plant population per unit area decreases the head weight simultaneously. Similarly, the possibility of competition for nutrients, light, air and moisture, as plant spacing is reduced, which resulted in decreased diameter and weight of cabbage heads [57].

Bulb dry weight

Significantly high ($P < 0.01$) main effect on average bulb dry weight of the crop plant was observed due to both cultivar and population density had highly. Nevertheless, the interaction effect of the two factors was not significant on this plant parameter (Table 3).

“Bombay Red” produced the heaviest average bulb dry weight (Table 5) which was about 32% more than that of “Adama Red”. The difference in average bulb dry weight between cultivars evaluated may be commensurate with the size and weight of individual bulbs. Similarly, significant difference between cultivars on bulb dry matter was reported which was also related to the fresh weight of respective cultivar [50]. Other author also reported that bulb dry matter content of onion depends on genotype difference [64].

Average bulb dry weight decreased significantly ($P < 0.01$) and consistently in response to increased plant population density. When population density increased from 25 to 33.33, 50, 66.67, 100, and 200 plants m^{-2}, the average onion bulb dry weight decreased by about 13, 31, 43, 66 and 97%, respectively. Bulb mean dry weights of the plant population densities of 50 and 66.67 plants m^{-2} were in statistical parity (Table 5). The highest mean bulb dry weight was recorded at the lowest population density (25 plants m^{-2}), whereas, the lowest was obtained at the highest population density (200 plants m^{-2}). The reduction in average dry weight of bulbs could be attributed to increase in competition for growth factors between neighbouring plants and reduced light use efficiency of onions as plant population density increases. In contrary, large plant size was obtained at wider space that allows intercepting of more sun light, maximize assimilate and accumulate more dry matter in the bulbs.

Similarly, high planting density significantly reduced average bulb dry weight [65]. The results are also consistent with other study which says that lower onion plant density (67 plants m^{-2}) significantly improved the average dry bulb weight per plant [66]. It was increased from 5.3 to 6.6 g/bulb. In addition, a study on carrot revealed that dry matter of carrots increased significantly as plant density was decreased [49].

Harvest index

Cultivar had significant ($P < 0.05$) main effect on harvest index whereas population density had no significant effect on this parameter. Furthermore, the interaction of cultivar and population density was not significant on harvest index (Table 3).

Bombay Red" produced higher harvest index (Table 5) which was about 9% more than that of "Adama Red. This could be due to its limited vegetative growth. Early maturing plants generally achieve higher values of harvest index, which is also true for the Bombay Red cultivar [67].

Bulb diameter

In this study, it was observed that both cultivar and population density had highly significant ($P < 0.01$) main effects on bulb diameter of onion. However, the interaction effect of the two factors was not significant on this plant parameter (Appendix Table 3).

Highly significant variation in bulb diameter was found between the tasted cultivars. "Bombay Red" cultivar scored about 19% larger bulb diameter compared to the diameter of "Adama Red" cultivar (Table 5). It is speculated that, this variation could be due to genetic differences between the cultivars. Similar observations among onion cultivars also reported by earlier studies [30, 45, 40]. Furthermore, difference in bulb diameter among cultivars was reported by [38].

Among plant population densities, the biggest bulb diameter was obtained for the lowest plant population density (25 plants m^{-2}), which is statistically similar with the values of 33.33 plants m^{-2} population density. In contrast, the smallest bulb diameter was obtained at the population density of 200 plants m^{-2}, which is significantly lower than the diameter of bulbs at 100 plants m^{-2} (Table 5). Bulb diameter decreased as plant population density increased with the lowest population density producing bulbs about 30% greater than those from the highest plant population density. This seems to indicate that, as plant population density increases, bulb size decreases.

One most probable reason for decreases in bulb size as population density increase is reduced number of leaves per plant which intern negatively affect the amount of assimilate production. Other possible reason could be more severe competition for growth factors (water and nutrients), between neighbouring plants.

This is in agreement with the findings earlier study reported that size of onion bulbs grown in high densities were smaller and irregular in shape [32]. Similarly, plant density increased, there was a progressive shift of the modal-size grade to smaller grades [61]. Furthermore, the result of the present study is supported by the previous result reported by [58, 34, 60, 40].

This result also confirms the previous findings on other crops; increase in head size for broccoli is asymptotic and that the head size approaches the maximum at relatively low densities (20,000 plants ha^{-1}) [69]. In addition, he reported that the head diameter of Gem and GSI decreased by about 50% as population density increased from 2,800 to 30,000 plants ha^{-1}. Cabbage head increased with decreased plant spacing (high population density) [57]. Similarly, widening plant spacing the size of bulb, weight of bulb and number of cloves per bulb gradually increased in garlic [33]. They further indicated that wider spacing favored better development of bulbs.

Percent bulb dry matter

Cultivar had no significant main effect on percent dry matter content of the bulbs. In contrast, population density indicated significant ($P < 0.05$) main effect while the interaction effect was non-significant (Table 3).

The cultivars showed comparable values of percent dry matter (Table 5). Similarly, study on tomato indicated no significant variations on percent dry matter content of fruits due to variety [70].

Increased plant population density significantly decreased percent dry matter content of onion bulb. The results showed that significantly higher percent dry matter was achieved at the lowest plant population density (25 plants m^{-2}) with gradual decrease to 6.27% percent dry matter being recorded at 100 plants m^{-2}, while significantly the lowest percent dry matter was obtained at the highest plant population density (200 plants m^{-2}) (Table 5). The decrease in percent dry matter content of onion bulbs at high plant population density could be attributed to sooner onset of bulbing that prevented further leaf production. This in turn may contribute to low photosynthesis and low assimilates partitioning to the bulbs as a storage organ. Earlier study reported that eight days earlier bulbing in onion plants at population density of 400 plants m^{-2} compared to those planted at a density of 100 and 200 plants m^{-2} [16]. These results are also in conformity with the findings of [57] who reported that heads of cabbage plants grown at narrower spacing (high

Table 5. Main effects of cultivar and plant population density on bulb fresh and dry weights, harvest index, bulb diameter and percent bulb dry matter.

Treatment	Yield Component Parameters				
	Bulb fresh weight (g)	Bulb dry weight (g)	Harvest index (%)	Bulb diameter (cm)	Percent bulb dry matter (%)
Cultivar					
Adama Red	52.63b	3.48b	63.87b	3.87b	6.52
Bombay Red	70.45a	4.61a	69.67a	4.59a	6.50
$LSD_{(5\%)}$	2.61	0.26	5.24	0.12	ns
Population density (plants m^{-2}**)**					
25	75.81a	5.45a	70.16	4.74a	7.22a
33.33	71.86a	4.84b	67.41	4.59a	6.72ab
50	64.07b	4.15c	64.27	4.31b	6.48bc
66.67	59.33bc	3.80c	66.12	4.05c	6.39bc
100	52.26d	3.28d	69.16	4.02c	6.27bc
200	45.89e	2.76e	63.47	3.64d	6.00c
$LSD_{(5\%)}$	4.52	0.46	ns	0.21	0.64
CV (%)	6.14	9.43	11.34	4.18	8.23

ns = non-significant at 0.05 probability level. Means sharing the same letter within a column are non-significantly different at 5% level of significance.

Table 6. Main effects of cultivar and plant population density on days to maturity, neck diameter and total soluble solid.

Treatment	Days to maturity (day)	Neck diameter (cm)	Total soluble solid (%)
Cultivar			
Adama Red	126.94a	0.86a	10.20
Bombay Red	113.78b	0.75b	10.77
$LSD_{(5\%)}$	6.19	0.07	ns
Population Density (plants m^{-2}**)**			
25	124.33	1.01a	11.54
33.33	122.17	0.91ab	10.94
50	121.50	0.82bc	10.69
66.67	120.83	0.77cd	10.33
100	118.17	0.698d	10.17
200	115.17	0.649d	9.24
$LSD_{(5\%)}$	ns	0.12	ns
CV (%)	7.43	12.66	11.71

ns = non-significant at 5% probability level. Means sharing the same letter within a column are non-significantly different at 5% level of significance.

population density) had less percent dry matter than heads of plants grown at wider spacing.

Days to Maturity

Cultivar had highly significant ($P < 0.01$) main effect on days to maturity while population density had no significant main effect. Moreover, cultivar and population density had no significant interaction effect on days to maturity (Table 3).

The result revealed that “Bombay Red” matured 13.16 days earlier than “Adama Red” (Table 6). Similar reports indicated that onion cultivars differ in bulb maturity, weight, size and yield when grown even in similar soil and climatic conditions due to their genetic differences [68]. Similarly, significant difference between garlic varieties on maturity days also reported by earlier study [54]. Bombay Red matured about 10 days earlier than Adama Red [23].

Neck Diameter

Analysis of the data revealed that both cultivar and population density had highly significant ($P < 0.01$) main effects on neck diameter of onion bulb. However, the interaction effect of the two factors was found not significant (Table 3).

The data presented in Table 6 showed that neck diameter of Adama Red was significantly thicker than that of Bombay Red by about 15%. The varation in neck diameter could be due to differences in genetic make up of the cultivars. This result is in conformity with the findings of earlier study reported that onion varieties significantly differed from one another with respect to bulb neck thickness [60]. Similarly, significant neck thickness difference between onion cultivars were reported [39].

Increasing plant population density led to significant ($P < 0.01$) reductions in neck bulb diameter. When plant population density was increased from 25 plants m^{-2} to 33.33 plants m^{-2}, neck diameter was not affected. However, when the population density was raised further to 50, 66.67, 100, and 200 plants m^{-2}, neck diameter reduced by about 23, 31, 45, and 56%, respectively. The neck diameters of plants grown at population densities of 50 and 66.67 plants m^{-2} however, were in statistical parity (Table 6). The decrease in neck diameter in response to increased plant population density could be attributed to the availability of progressively lower amount of photosynthate due to the increasing competition among plants for growth factors. Positive association between neck thickness and bulb diameter were reported by [71]. The present result is consistent with earlier study [72] and other author reported that lower planting density significantly increased neck thickness of bulbs [60]. Bulbs of thick neck in plots of lowest planting density (20 plants m^{-2}) while the plots of highest density (40 plants m^{-2}) contained bulbs of less neck diameter [39].

Total Soluble Solid

Cultivar, population density and their interaction did not show significant effects on total soluble solid content of the crop plant (Table 3).

Marked variations were not observed in total soluble solid content between the cultivars tested, with nearly equal percentages of total soluble solid obtained (Table 6). Among plant population densities evaluated in this study, thinly populated plots (25 plants m^{-2}) tended to have high values of total soluble solid whereas the minimum values of total soluble solid was obtained for plants grown in thickly populated plots (200 plants m^{-2}) (Table 6). Generally, as plant population density increased, total soluble solid tended to decrease. This tendency could be attributed to the relative decrease in dry matter content of onions as plant population density increased. No significant variations in total soluble solid content of tomato fruits due to the main effects of variety, plant density and their interactions [71].

CONCLUSIONS

In general, it could be deduced that plating onion at highest population density (200 plants m^{-2}) could out-yield those of lower densities. However, optimum bulb size for fresh market use is generally contradictory whereas market in the study area accepts a bulb size of 20 g as marketable; the national recommendation for onion bulb size is 60 g. Thus, compromise decisions must be made for wider market and, hence, it could be recommended that preferred onion bulb size could be achieved by adopting 66.67 plants m^{-2} population density. Moreover, additional research on the cultivars for more seasons and under different agro-ecological conditions is suggested to draw a conclusive recommendation.

REFERENCES

[1] Hanelt, P., 1990. Taxonomy, Evolution and History. pp. 1-26. In: Onions and Allied Crops, H.D. Rabinowitch, and J.L. Brewster, eds., CRC Press Inc, Boca Raton, Florida, USA.

[2] Simon, P.W., 1992. Onion improvement newsletter for 1991. Dept of Horticulture, University of Wisconsin, Madison, Wisconsin, USA.

[3] Fritsch, R.M. and N. Friesen, 2002. Evolution, domestication and taxonomy. pp. 5-30. In: Allium Crop Science: Recent Advances, H.D. Rabinowitch, and L. Currah, eds., CABI Publ., Wallingford, UK.

[4] Corgan, J.N. and N. Kedar, 1990. Onion cultivation in subtropical climates. pp. 31-47. In: Rabinowitch, H.D. and J.L. Brewster (eds.), Onions and Allied Crops Vol.2.CRC Press, Boca Raton, Florida.

[5] Randle, W.M. and C.A. Ketter, 1998. Pungency assessment in onions. Proceedings of the 19-workshop conference of the Association for Biology Laboratory Education (ABLE). pp 177-196.

[6] Decoteau, D.R., 2000. Vegetable crops. Prentice-Hall, inc. USA. 561p.

[7] Vohra, S.B., M. Rizaman and J.A. Khan., 1994. Medical uses of common Indian vegetables. Planta Medea., 23(4): 381-393.

[8] FAOSTAT, 2010. Statistical database and data sets. http://faostat.fao.org (Accessed 13 March 2011).

[9] Mangal, J.L., S. Lal and P.S. Hooda, 1989. Salt tolerance of the onion seed crop in India. *Journal of Horticulture Science,* 64(4): 475-477.

[10] Pathak, C.S., 1993. Allium improvement for the tropics: Problems and AVRDC strategy. Proceedings of the first International Symposium on Allium for the Tropics. *Acta Horticulture,* 358:79-86.

[11] Metasebia, M. and Shimelis, H., 1998. Proceeding of the 15th Annual Research and Extension Review Meeting, 2 April 1998. Alemaya Research Centre. Alemaya University of Agriculture. pp. 216-235.

[12] Lemma, D. and E. Herath, 1994. Agronomic studies on Allium. pp. 139-145. In: Herath and Lemma(Eds.). Horticultural research and development in Ethiopia. Proceeding of the 2nd national horticultural workshop of Ethiopia. 1-3 December 1992. Institute of Agricultural Research and Food and Agriculture Organization. Addis Ababa, Ethiopia.

[13] Shemelis A., 1997. Onion research and production in Ethiopia. *Acta Horticulture.* (ISHS) 433: 95-98. http://www.actahort.org/

[14] Lemma, D. and Shimelis, A., 2003. Research experience in onion production. Research Report Number, 55, EARO, Addis Ababa, Ethiopia.

[15] CSA, 2009. Report on land utilization. Statistical Bulletin, Vol.417. Addis Ababa, Ethiopia. 341p.

[16] Mondal, M.F., 1991. Factors controlling the process of bulbing in onion (*Allium cepa* L.). *Bangladish Journal of Agricultural Science*, 18: 65-70.

[17] Brewster, J.L., 1994. Onions and other vegetable Alliums. CABI Publishing. Wallingford, UK. 236p.

[18] Lemma, D., 2004. Onion production pamphlet (Amharic version). Melkassa Research Centre.

[19] Geremew, A., Teshome, A., Kasaye, T., and Amenti C., 2010. Effect of intra-row spacing on yield of three onions (*Allium cepa* L.)Varieties at Adami Tulu agricultural research center, mid rift valley of Ethiopia. *Journal of Horticulture and Forestry,* 2(1): 007-011.

[20] Zubeldia, A. and J.L. Gases, 1977. The effect of spacing and the number of stem on the earliness and total yield of tomato cultivars. Production vegetable, 7:73–97.

[21] Rashid, M.A., and M.M. Rashid, 1976. Effect of spacing on the yield of onion. *Bangladesh Journal of Horticulture,* 4: 18-22.

[22] Roy, R.N., A. Finck, G.J. Blair and H.L.S. Tandon, 2006. Plant nutrition for food security. A guide for integrated nutrient management. Food and Agriculture Organization of the United Nations. FAO Fertilizer and Plant nutrition Bulletin 16. Rome.

[23] EARO, 2004. Directory of released crop varieties and their recommended cultural practices**.** Addis Ababa. pp. 26-27.

[24] Waskar, D.P., R.M. Khedlar and V.K. Garande, 1999. Effect of postharvest treatment on shelf life and quality of pomegranate in evaporative cool chamber and ambient conditions. *Journal of Food Science and Technology,* 2(36): 114-117.

[25] Resende, G.M., N.D. Costa and C.S. Dias, 1999. Population densities for onion production in the Sao Francisco valley. Comunicado Tecnico Centro de Pesquisa Agropecuaria do Tropico Semi Arido. 81: 4

[26] Walkley, A. and I.A. Black, 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37: 29-38.

[27] Olsen, S.R., C.V. Cole, F.S. Watanable and L.A. Dean, 1954. Estimation of Phosphorus in soils by extraction with sodium bicarbonate. USDA, circular. pp. 939:1-19.

[28] Murphy, J. and J.P. Riley, 1962. A modified single solution method for the determination of phosphate in natural waters. *Anal. chim. Acta*, 23: 31-36.

[29] SAS, 2002. SAS/STAT guide to personal computers, version 9.0. Statistical analysis system institute Inc. NC. USA.

[30] Mohanty, B.K. and A.M. Prusti, 2001. Performance of common onion varieties in kharif. *Journal of Tropical Agriculture,* 39: 21-23.

[31] Mishra, T.D., 2010. Evaluation of garlic (*allium sativum* l.) germplasms for yield potential and quality characters under allahabad agro-climatic conditions. PhD Dissertation presented to Allahabad School of Agriculture of Deemed to be University. pp. 15-27.

[32] McGeary, D.J., 1985. The effects of plant density on the shape, size, uniformity, soluble solids content and yield of onions suitable for pickling. *Journal of Horticulture Science,* 60 (1): 83-87.

[33] Lawande, K.E., R.D. Pawar, V.S. Supe and P.M. Kale, 1994. Effects of spacing on yield and yield contributing in garlic. pp. 96. In: First International Symposium on Edible Alliaceae, Abstracts. March 14-18, 1994, Mendoza, Republica Argentina.

[34] Khan, M.A., M.K. Hasan, M.A.J. Miah., M.M. Alam and A.S.M.H. Masum, 2003. Effect of plant spacing on the growth and yield of different cultivars of onion. *Pakistan Journal of Biology Science,* 6(18):1582-1585.

[35] Om, H. and R.P. Srivastava, 1977. Influence of the planting material and spacing on the growth and yield of garlic. *Indian Journal of Horticulture,* 34(2/3):152-156.

[36] Jilani, M.S., M.Q. Khan and S. Rahman, 2009. Planting densities effect on yield and yield components of onion (allium cepa L.), *Pakistan Journal of Agriculture Research*, 47(4): 397- 404.

[37] Bodnar J.L., B. Schumacher and S. Uyenaka, 1998.

legumes. *New Zealand Journal of Agronomy,* 29: 9-15.

Garlic production in Ontario. Omafra Factsheet, Canada. pp.1-8.

[38] Kimani, P.M., J.W. Karinki, R. Peters, H.D. Robinowch and D.J. Midomore, 1993. Potential of onion seed production in tropical environment. International symposium on Alliums for the tropics. *Acta Horticulture,* 358: 341-348.

[39] Ghaffoor, A., M.S. Jilani, G. Khaliq and K .Waseem, 2003. *The* effect of different NPK levels on the growth and yield of three onion (*Allium cepa* L.) varieties. *Asian Journal of plant sciences,* 2: 342-346.

[40] Jilani, M.S., P. Ahmed, K. Waseem and M. Kiran, 2010. Effect of plant spacing on growth and yield of two varities of onion (*allium cepa* L.) Under the agro-climatic condition of D. I. Khan. *Pakistan Journal of Science*, 62(1): 37- 41.

[41] Bosch Serra, A.D. and F. Domingo Olivé, 1999. Ecophysiological aspects of nitrogen management in drip-irrigated onion (*Allium cepa* L.). *Acta Horticulture,* 506: 135–140.

[42] Singh, N.P. and R.A. Singh, 2002. Scientific crop production, X press Graphics, Delhi- 28, first ed., India

[43] Purushottam P.K., 2001. Plant spacing: a key husbandry practice for rainy season cabbage production. *Nepal Journal* of *Agriculture Research,* 4/5:48-55.

[44] Sinclair, T.R. and R.C. Muchow, 1999. Radiation use efficiency. Adv. Agron. 65: 215-265.

[45] Ijoyah, M.O., H. Rakotomavo and M.V. Naiken, 2008. Yield performance of four onion (*Allium cepa* L.) cultivars compared with the local variety under open field conditions at Anse Boileau. *Seychelles Journal of Science and Technology,* 28(3):28-33.

[46] Shakarami, G. and M. Rafiee, 2009. Response of corn (*Zea mays* L.) to planting pattern and density in Iran. *American-Eurasian Journal of Agriculture and Environmental Science,* 5(1): 69-73.

[47] Daroish, M., Z. Hassan and M. Ahad, 2005. Influence of planting dates and plant densities on photosynthesis capacity, Grain and biological yield of soybean (*Glycine max* (L.) Merr.) in karaj. *Iran Journal of Agronomy,* 4(3): 230-237.

[48] Egli, D.B, 1988. Plant density and soybean yield. *Crop Science,* 28: 977-981.

[49] Abiyot, S., 2008. Effect of seed bed preparation and plant density on root yield and quality of carrot(*Daucus carota* L). An MSc Thesis presented to the School of Graduate Studies of Haramaya University. pp. 26-40.

[50] Cheema, K.L., A. Saeed and M. Ahmad, 2002. Autumn crop production through sets in eight onion cultivars. *Pakistan International Journal of Agriculture Biology,* 4(4): 547–549.

[51] Ayaz, S.B., A. Mckenzie, B.A. Hill and D.L., Mcneil, 2004. The effect of plant population on dry matter accumulation, yield and yield components of four grain

[52] Hussain, A., M. Nawaz and F.M. Chaudhry, 2000. Radiation interception and utilization by chickpea at different sowing dates and plant populations. *Journal of Agriculture Science*, 3(2): 21-25.

[53] Jilani, M.S., 2004. Studies on the management strategies for bulb and seed production of different cultivars of onion (*Allium cepa* L.). PhD Dissertation Presented to Departement of Horticulture faculty of Agriculture of Gomal University. pp. 120-141

[54] Shrestha, R.L., Karki, T. and A. Pun, 2000. Performance evaluation on garlic genotypes in the research command area of lumle, during 1998-1999. Working Paper, Lumle Agricultural Research Centre, 3:5.

[55] Stofella, P.J., 1996. Plant arrangement and density of transplants influence on sweet Spanish onion yield and bulb size. *Horticulture Science,* 31: 129-130.

[56] Kanton, R.A., L. Abbey, R.G. Hilla, M.A. Tabil, and N.D. Jan, 2002. Influence of transplanting age on bulb yield and yield components of onion (*Allium cepa* L.) in northern Ghana. *Journal of Vegetable Crop Production,* 8:27-37.

[57] Dragan Ž., K.M. Nina, O. Jože, P. Tomaž and T. Stanislav, 2007. Yield and quality of early cabbage (*Brassica oleracea* L. var. capitata) in response to within-row plant spacing. *Acta Agriculture*, 89 (1):15-23.

[58] Singh, R.V., 1995. Response of onion to plant spacing, nitrogen phosphorus fertilization. *Journal of Research Bisra Agriculture University*, **7**: 141-143.

[59] Guerra, M., 1988. Effect of sowing date and planting density on the yield of three onion cultivars. *Horticulture Abstracts,* 58(6):3361.

[60] Dawar, N.M., F.K. Wazir, M.D. Dawar and S.H. Dawar., 2005**.** Effect of planting density on the performance of three varieties of onion under the agro-climatic conditions of Peshawar. *Sarhad Journal of Agriculture,* 21(4): 546-549.

[61] Rogers, I.S., 1977. The influence of plant spacing on the frequency distribution of bulb weight and marketable yield of onions. *Journal of Horticultural Science,* 53: 153-161.

[62] Dellacecca, V. and A.F.S. Lovato, 2000. Effects of different plant densities and planting in Onion (*Allium cepa* L.) II. The influence of red: far-red spectral ratio and of photon flux density. *Annals of Allium cepa Botany*, 58: 197-206.

[63] Castellanos, J.Z., P. Vargas-Tapia, J.L. Ojodeagua, G. Hoyos, G. Alcantar-Gonzalez, F.S. Mendez, E. Alvarez-Sanchez and A.A. Gardea, 2004. Garlic productivity and profitability as affected by seed clove size, planting density, and planting method. *Horticulture Science*, 39 (6): 1272-1277.

[64] Islam, M.K., M.F. Alam and A.K.M.R. Islam, 2007. Growth and yield response of onion (*Allium cepa* l.) genotypes to different levels of fertilizers. *Bangladesh*

Journal of Botany, 36(1): 33-38.

[65] Farragg, M.M., 1995. Influence of planting method and plant density on growth, yield and bulb quality of onion grown from sets. *Assiut Journal of Agriculture Science*, 26: 73-84.
[66] Azmi, M.A.R. and N.A. Al-Hadidi, 2005. Onion production and nitrogen uptake in response to different doses of urea fertilizer at two different plant populations. King Saud University *Jornal of* Agricultural *Science,* 18 (1): 19-34.
[67] Dantuma, G. and R.Thompson, 1983. Whole crop physiology and yield components. pp. 143-58. In: Hebblethwaite, P.D. (ed.), the faba bean *(Vicia faba L.).* A basis for improvement Butterworth, London, UK.
[68] Ramirez, D. and W. Kline, 1992. Growing onions in Honduras: problems and investigations. Onion newsletter for the tropics. pp.4:10-14.
[69] Chung, B., 1982. Effects of plant-density on the maturity and once-over harvest yields of broccoli. *Journal of Horticulture Science,* 57: 365-372.
[70] Dugma, A., 2000. Variety and population density influence on fruit yield and quality of processing type tomatoes. An MSC Thesis presented to the school of Graduate studies of Haramaya University. pp. 36-37.
[71] Patil, R.S. and P.N. Kale., 1985. Correlation studies on bulb characteristics and storage losses in onion. Maharashtra University*. Journal of Agriculture,* 10: 38.
[72] Chaudhry, M.F., K. Mahmood, M.A. Khan and A. Qadir, 1990. Effect of plant density on plant growth, size and yield of onion (*Allium cepa L.*). *Pakistan Journal of Agriculture Research*, 11 (4): 239-242.

APPENDICES

Appendix Table 1. Mean square values of plant height 30 DAT and at maturity, leaf number per plant 30 DAT and at maturity, leaf length 30 DAT and at maturity and bolting percentage as influenced by cultivar, plant population density and their interaction.

Source of variation	d.f	Plant height 30 DAT	Plant height at maturity	Leaf no. per plant 30 DAT	Leaf no. per plant at maturity	Leaf length 30 DAT	Leaf length at maturity	Bolting percentage
Replication	2	19.41	134.19	0.27	4	0.29	2.14	0.01
Cultivar(A)	1	3.43	346.64*	0.04	0.29	14.87	158.47*	20.78**
Population density(B)	5	13.97	229.86**	0.09	19.75**	5.08	65.75*	4.21**
A X B	5	2.99	20.16	0.04	1.29	2.66	19.94	1.10**
Error	22	8.3	54.21	0.26	3.72	4.6	26.01	0.01
CV (%)		12.69	12.45	10.61	12.08	13.07	13.11	7.87

d.f, degree of freedom; *, **; significant at p <0.05, <0.01, probability level, respectively.

Appendix Table 2. Mean square values of shoot fresh and dry weights, biological fresh and dry matter yields as influenced by cultivar, plant population density and their interaction.

Source of variation	d.f	Shoot fresh weight	Shoot dry Weight	Biological fresh matter yield	Biological dry matter yield
Replication	2	19421335.8	18368.53	137480039.00*	1369833.3
Cultivar (A)	1	4249706.7	95975.01	3006629193.00**	7011180.20**
Population density (B)	5	177534564.60**	1524693.78**	3141921207.00**	47186971.40**
A X B	5	6225937.7	16260.81	82184303	2109507.2
Error	22	2851079	30095.23	36505173	832377
CV (%)		18.32	15.79	15.66	21.18

d.f, degree of freedom; *, **; significant at p <0.05, <0.01, probability level, respectively.

Appendix Table 3. Mean square values of bulb fresh and dry weights, harvest index, bulb diameter, percent bulb dry matter, days to maturity, Neck diameter and total soluble solid as influenced by cultivar, plant population density and their interaction.

Source of variation	d.f	Bulb fresh weight	Bulb dry weight	Harvest index	Bulb diameter	Percent bulb dry matter	Days to maturity	Neck diameter	Total soluble solid
Replication	2	56.22*	0.31	15.5	0.33**	0.11	25.53	0.24**	0.14
Cultivar (A)	1	2859.04**	11.41**	303.28*	4.64**	0.01	1560.25**	0.11**	2.97
Population density (B)	5	783.23**	5.90**	42.16	0.99**	1.06*	62.83	0.11**	3.65
A X B	5	15.33	0.16	93.93	0.04	0.23	2.65	0.01	0.93
Error	22	14.28	0.15	57.36	0.03	0.29	80.07	0.01	1.51

CV (%)		6.14	9.43	11.34	4.18	8.23	7.43	12.66	11.71

d.f, degree of freedom; *, **; significant at p <0.05, <0.01 probability level, respectively.

Appendix Table 4. Mean square values of yield parameters as influenced by cultivar, plant population density and their interaction.

Source of variation	d.f	Number of marketable bulbs	Weight of marketable bulbs	Number of unmarketable bulbs	Weight of unmarketable bulbs	Total bulb yield
Replication	2	4423521613.1	2491119	80276709.00	37867.62	3193098
Cultivar (A)	1	1821217.73	150221670*	102443851.00	1263.21	190904377*
Population density (B)	5	2.2443658E12**	1089730122**	10996646878.00**	6207149. 84**	1253623899**
A X B	5	378814787.6	59122910	70754595.00	9842.42	43702837
Error	22	3090789516.9	26660607	36011997	62667.38	27017765
CV (%)		7.37	18.41	15.29	16.44	17.73

d.f, degree of freedom; *, **; significant at p <0.05, <0.01, probability level, respectively.

Appendix Table 5. Monthly weather data of Bir Farm Private Limited Company, December 2009–May 2010

Weather	Month					
	Dec.	Jan.	Feb.	Mar.	Apr.	Ma.
Rainfall (mm)	15.5	0.1	0.12	0.33	1.11	4.52
Temperature (^{0}C)						
Minimum	10.9	11.53	13.54	13.78	16.92	16.98
Maximum	29.7	30.96	32.4	32.6	33.12	29.28
Relative humidity (%)	55	50.94	57.86	44.16	34.77	58.42

Appendix Table 6. Analytical results of some soil physico-chemical properties

Depth (cm)	pH (water)	OC (%)	TN (%)	Available P(ppm) Olsen	Exchangeable K (meq/100g soil)	Particle size distribution			
						% Clay	% Silt	% Sand	Soil Class
0-30	6.29	2.1	0.1	6	1.43	75	20	5	Heavy Clay

Appendix Table 7. Details of treatment combinations.

Cultivar	Spacing in meters	Equivalent area (m^2)	Plants per m^2	Plants per ha
C_1	0.4 x 0.1	0.04	25.00	250,000
	0.3 x 0.1	0.03	33.33	333,300
	0.2 x 0.1	0.02	50.00	500,000
	0.3 x 0.05	0.015	66.67	666,700
	0.2 x 0.05	0.01	100.00	1,000,000
	0.1 x 0.05	0.005	200.00	2,000,000
C_2	0.4 x 0.1	0.04	25.00	250,000
	0.3 x 0.1	0.03	33.33	333,300
	0.2 x 0.1	0.02	50.00	500,000
	0.3 x 0.05	0.015	66.67	666,700
	0.2 x 0.05	0.01	100.00	1,000,000
	0.1 x 0.05	0.005	200.00	2,000,000

Notes: C_1=Adama Red; C_2= Bombay Red