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Effect of planting density on yield components and yield of Groundnut (Arachis hypogaea L.) varieties at Abeya, Borena Zone Southern Ethiopia

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Abstract: *Determining optimum plant density for groundnut varieties is imperative to maximize productivity of the crop. A field experiment was conducted at Abeya District Borena Zone, southern Oromia Ethiopia, from May to October in 2013 and 2015 to determine the effect of plant density on yield components and yield of groundnut varieties. The experiment was laid out in RCBD in factorial arrangement with three varieties of groundnut (Tole-1, Fayo and NC-4x) and five plant densities (142847, 166666, 200000, 250000 and 333333 plants ha^{-1}) in three replications. There was significant interaction effect of varieties and plant density on above ground dry biomass, number of pegs per plant, total pods per plant, number of matured pod per plant, dry pod yield, seed yield and harvest index. T*he highest above ground dry biomass (**6050** kg ha^{-1}) recorded for the variety "NC-4x" at the highest plant density of (*333333 plants ha^{-1}). The variety "Tole-1" at plant density of (*142857 *plants ha^{-1}) gave the highest number of pegs per plant (78.83 pegs per plant) and total pod per plant (77.33 pods per plant). Likewise, the variety "Tole-1" at plant density of (*142857 *plants ha^{-1}) gave the highest number of matured pod per plant (73 pods per plant). The variety "Tole-1" at plant density of (*250,000 *plants ha^{-1}) gave the highest dry pod yield (*3,831 kg *ha^{-1}) and* the highest seed yield (**2,790** kg ha$^{-1)}$ *as well as highest harvest index (***36.5***). From this study it can be concluded that the appropriate plant densities for higher seed yield for varieties 'Tole-1' and NC-4x' was 250,000 plants ha^{-1} (40cm × 10cm), while 200,000 plants ha^{-1} (50 cm × 10cm), for the variety 'Fayo'. Among the varieties, 'Tole-1' was found to be high yielder in the study area.*

Keywords*: Biomass, harvest index, Interaction effect, Leaf area index, Pod yield, Seed yield*

1. INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is a legume crop belonging to the family Fabaceae. It is an important oil crop of South American origin (Bolivia and adjoining countries) and is cultivated in tropical and warm temperate climates. The word *A. hypogaea* has been derived from two Greek words *Arachis* meaning a legume and *hypogaea* meaning below ground (referring to the formation of pods in the soil) [1]. The annual world groundnut production was around 38.2 million tunes from 26.4 million ha of production area [2]. Developing countries constitute 97% of the global area and 94% of the global production of this crop [3]. Groundnut was probably introduced to northern Ethiopia by the Portuguese in the 17th century, and somewhat later through the Arab influence to south eastern part of the country [4]. It is one of the three economically important oilseed crops including noug (*Guizota abyssinica*) and sesame

(*Sesamum indicum*) in Ethiopia and largely produced in the eastern part of the country [5].

The estimated production area and yield of groundnut in Ethiopia in 2013/2014 cropping season were 79,947.03 ha and 112,088.72 tons, respectively, and the largest groundnut production areas are in Oromia (52,921 ha), Benshangul-Gumuz (18,592.72 ha), Amhara (2,380.15 ha) and in SNNPR (376.33 ha) [6]. However, it is important to note that the national average yield of groundnut (1.4 t ha^{-1}), is much lower than the average potential yield for improved groundnut varieties, which can amount to 3.5 and 8.0 t ha^{-1} of dry pods under rain-fed and irrigation conditions, respectively [7]. Plant density and planting arrangement are efficient management tools for maximizing crop yield by optimizing resources utilization such as light, nutrients and water and reduce soil surface evaporation [8].

Optimum plant population density in groundnut varies between environments, cultivars and management practices. Planting density of groundnut is often low (<100,000 plants ha^{-1}) in farmers' fields [9] and especially when the crop is not grown in rows resulting in low yields. [10]. had reported a spacing of 30 cm x 30 cm (111,111 plants ha^{-1}) in Tanzania, 60 cm x 30 cm (55,556 plants ha^{-1}) in West Africa. In Ethiopia, although the groundnut varieties vary in terms of growth habits, days to maturity etc. the recommended spacing for all the varieties is 60 cm ×10 cm irrespective of climatic and soil variations in different agro-ecologies [11]. Recently, there has been a substantial increase in growing of groundnut both as a food and cash crop in Abeya, Galana and Dugdadawa districts of Borana zone, southern Ethiopia. However, there are no recommendations on optimum plant density for groundnut varieties with different growth habit to increase the productivity of the crop. Therefore, this study was undertaken to determine the appropriate planting density for major groundnut varieties grown in the study area.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

Field experiment was conducted in Abeya District, southern Oromia Ethiopia, from May to October in 2013 and 2015. The experimental site (Abeya) is found in southern Ethiopian rift valley 365 km away south from Addis Ababa. The altitude of the site is 1492 m a.s.l. (give latitude and longitude of the site). Annual total rainfall of the site was (219.4mm and 126.2mm) with average mean temperature (12.8°C and 12.1°C) during the 2013 and 2015 respectively(Figure 1&2).

2.2. Treatments and Experimental Design

Three released varieties of groundnut (Tole-1, Fayo and Nc-4x) and five planting densities were tested in Randomized **C**omplete Block Design in factorial arrangement with three replications. The densities were 142857 plants ha^{-1} (70 cm × 10cm), 166,666plantsha^{1}(60cm × 10 cm), 200,000 plants ha^{-1} (50 cm × 10 cm), 250,000 plants ha^{-1} (40 cm × 10 cm) and 333,333 plants ha^{-1} (30 cm × 10 cm).The gross plot size was 2.4 m × 3.6 m for the width and length of the plots, respectively. The number of rows were 12 for inter-row spacing of 30 cm; 9 for the inter row spacing of 40 cm; 7 for the inter-row spacing of 50 cm; 6 for the inter-row spacing of 60 cm and 5 for the inter row spacing of 70cm. The data were collected from the central rows, by leaving one border rows from each side of a plot and one plant at the two ends of every row. The numbers of rows harvested were 10 for inter-row spacing of 30 cm; 7 for the inter-row spacing of 40 cm; 5 for the inter row spacing of 50 cm; 4 for the inter-row spacing of 60 cm and 3 for the inter-row spacing of 70 cm.

2.3. Soil Sampling and Analysis

Soil samples were collected from five spots from the experimental field before planting diagonally at a depth of 0-30 cm. The collected soil samples were dried in open air, ground, sieved and composited and analyzed for texture, soil pH, total nitrogen, organic carbon content, available phosphorus (P) and action exchange capacity (CEC). Soil samples were analyzed at Ziway soil laboratory for the selected physicochemical properties of the soil following the standard procedures.

2.4. Properties of Experimental Soils

The results of analysis of major physicochemical properties for the top soil (0-30 cm) taken before planting is indicated in Table -1. According to the laboratory analysis, the soil texture of the experimental area was clay loam. Thus, the soil texture of the study site is suitable for groundnut production as the crop is grown mostly on light-textured soils ranging from coarse and fine sands to sandy clay loams [12]. The soil pH of the study site was 5.7, which was acidic. Groundnut is one of the most acid tolerant crops [13] and grows best in pH ranging from 5.5 to 6.5 [12]. The CEC of the soil of the experimental site was analyzed to be 20.2 cmol (+)/kg (Table 2). Soils having CEC of >40, 25-40, 15-25, 5-15, <5 cmol (+)/kg were categorized as very high, high, medium, low and very low respectively [14]. Therefore, CEC of the experimental soil lies in a medium range which means the soil has moderate capacity to hold and exchange cations.

Further, the analysis indicated that the experimental soil had total nitrogen 0.347% and organic carbon content of 2.46%. According to [14], soils having total N of greater than 1.0% are classified as very high, 0.5-1.0% high, 0.2-0.5% medium, 0.1-0.2% low and less than 0.1% as very low. Hence, the total nitrogen content of the experimental soil (0.347) lies in the medium range. The Ministry of Agriculture and Fisheries also classified soils for organic carbon contents (%) as >3.50, 2.51-3.5, 1.26-2.50, 0.60-1.25 and <0.60 as very high, high, medium, low and very low, respectively [15]. Accordingly, the soil of the experimental site had medium organic carbon (2.46%) which could be attributed to the addition of organic materials in the form of crop residues from the previous crops. The available phosphorus of the experimental soil was 12.04 ppm (Table 3). [16], described soils with available P <10, 11-31, 32-56, >56 ppm as low, medium, high and very high, respectively. Based on this classification, the available P of the experimental soil lies in a medium range.

Table-1. Major physicochemical characteristics of the experimental soil

Soil characters Values	Soil characters Values
pH (by 1: 2.5 soil water ratio	5.70
Total nitrogen (%)	0.347
Organic carbon (%)	2.46
Available phosphorus (ppm)	12.04
Cation exchange capacity (cmol(+)/kg)	20.20
Soil texture:	
Sand (%)	44
Clay (%)	34
Silt (%)	22
Textural class	Clay loam

2.5. Management of the Experiment

The land was ploughed once, harrowed twice and leveled to obtain the desired germination and growth of crop. The field was then divided into three blocks and then in to 2.4m x 3.6m equal plots as per the treatments. Seeds of groundnut varieties used for this experiment were obtained from Yabello Pastoral and Dry-land Agriculture Research Center, south Oromia

Ethiopia. The seeds were sown in rows at the depth of 3 - 4 cm. Two seeds were planted per hole and then thinned to one plant per hill just a week after emergence. Planting was done on 2nd of May 2013 and 7th of May 2015. Hand weeding and cultivation were started two weeks after planting and continued at two weeks interval until the time of peg formation in which one hoeing and two hand weeding were done to control weeds. Harvesting was done when the crop reached physiological maturity, *i.e.* the pods fully veined, kernels have begun to become red in color and the inside of the shells has begun to color brown and show darkened veins. The net plots were harvested by digging out the whole plant with a hoe. Thereafter, the pods were picked from the main bunch and allowed to air and sundry for six days.

2.6. Crop Data Collected

Number of pegs and total pods per plant was determined from five randomly taken plants per net plot area at harvest while fully filled and sound pods were recorded from five randomly taken plants from the net plot area for determination of number of mature pods per plant. Similarly, number of seeds per pod was counted from 10 pods from net plot at harvest and hundred seed weight was recorded by counting hundred seeds from a bulk of shelled seeds and weighed using a sensitive balance. Dry pod yield was determined from the net plot after sun drying the harvested pods for 6 days and expressed in kilograms per hectare and shelling percentage was determined by taking sample of about 200g mature pods per plot as: $SP = \frac{SY}{PY} * 100$; where SP = shelling percentage; SY = seed yield; and PY = pod yield. Then seed yield was determined as shelling percentage multiplied by dry pod yield and the seed yield was adjusted to 8% moisture content.

2.7. Data analysis

The data were subjected to analysis of variance (ANOVA) according to the Generalized Linear Model (GLM) appropriate to factorial experiment in RCBD [17] using SAS version 9.20 [18]. computer software. As there error variances of the two years were homogeneous, combined analysis of variance was used. Significant differences among treatments were compared using the Least Significant Difference test at 5% level of significance.

3. RESULTS AND DISCUSSIONS

3.1. Crop Phenology

3.1.1. Days to 50% emergence

Emergence through the soil, known as 'cracking', began six to fourteen days after planting. Dry or cool soils can delay emergence for up to three weeks, often resulting in poor establishment due to soil-borne disease. The interaction of the two factors showed highly significant ($P<0.01$) effect on days to 50% emergence while the effect of year on variety and planting density showed non-significant effect (Appendix Table 1). The number of days from sowing to seedling emergence varied from 7 to 9.3 days. Two varieties (Tole-1 and NC-4x) took longer time (9.3) days to 50% emergence respectively (Table-1). Among the varieties, 'Fayo' with bunch growth habit emerged early (7days) while the rest two varieties 'Tole-1 and NC-4x' emerged lately (9.3 days) (Table 2). This result may be attributed to the difference of varieties in their dormancy periods. The result agrees with the findings of ([19], who reported that the runner market types of groundnuts varieties are late maturing and seeds are more dormant. While in subspecies *fastigiata* involving *var. fastigiata* (Valencia market class) and *var. vulgaris* (Spanish market type), bunch type varieties are early-maturing but generally lack fresh seed dormancy.

3.1.2. Days to 50% flowering

According to the result of analysis of Variance, the interaction of the variety and plant density were highly significant ($P<0.01$) on days to 50% flowering of groundnut (Appendix Table 1). Moreover, the interaction effect of year, variety and plant density found to be non-significant (P<0.05) on days to 50% flowering of groundnut. Variety 'Fayo' which was planted at planting density of 333,333 plants ha^{-1} was the first to reach its 50% flowering at (36.3 days) while variety "NC-4x" planted at the density of 142,587 plants ha^{-1} flowered late (45.7 days) (Table 2). The result also revealed that the crops flowered earlier (36.3 days) when planted at higher planting densities (333,333 plants ha^{-1} (30cm x 10cm) and flowered late (45.7 days) when planted at lower plant density (142,857 plants ha^{-1}(70cm x 10cm) (Table 2). This may be due to the genetic difference among the varieties and increased resource utilization efficiency in higher plant population densities. [20], reported varying growth patterns in some groundnut genotypes which could be due to differences in their genetic makeup. In agreement with this result, [21] reported that high plant density promotes Phenological development; with flowering occurring 14 days earlier in the highest plant density in lentil. Flowering is a very important physiological process in the development of the groundnut crop and has a profound effect on the final yield that can be obtained. In their study on groundnut, [22] reported that groundnut genotypes which flower early show greater synchrony and those which produce most of the flowers during 1st and 2nd weeks of flowering period produce greater numbers of pods [23]. The present result agreed with that of [24] who reported that sesame from the lower densities flowered significantly later than that of higher density. Moreover, [25] reported significantly delayed flowering of sunflower planted at wider spacing than the denser. On the other hand, increased plant density in faba bean did not significantly affect the days to flowering but hastened uniformity in maturity [26].

3.1.3. Days to 90% maturity

The analysis of variance showed that both the main effects of planting density and variety as well as the interaction effect of the two factors were highly significant (P<0.01) on days to physiological maturity. Whereas, the interaction effect among the three factors Year, Varity and Planting Density found to be none significant (Appendix Table 1). The two varieties 'NC-4x' and 'Tole-1' at plant density of 142,857 plants ha^{-1} took maximum number of days to maturity (155 days) while the minimum days to maturity (147.7) was recorded for variety 'Fayo' at the highest plant density of 333,333 plants ha^{-1} (Table 2). The days to maturity of groundnut cultivars was generally shorter at the higher plant densities than at lower densities regardless of the year and variety difference. This effect could be due to the fact that the crop growth rate increased as plant density increased [27]. The interaction effect indicated that the response of the varieties differed with the difference in plat population densities. This result was in line with that of [28] who reported that the maturity date of safflower was affected by planting density and cultivar where with increasing the planting density from 20 to 40 plants/m^2, number of days from sowing to maturity was significantly decreased. In contrast to this result, [29] reported that the closer row and plant spacing increased maturity days of safflower.

3.2. Growth parameters

3.2.1. Number of leaves

The interaction effects of variety and plant density on number of leaves per plant was significant (P<0.05) while the main effect of the two factors were found highly significant (P<0.01) (Appendix Table 1). The highest number of leaves per plant (485.7) was recorded from the spreading type variety 'Tole-1' while the lowest (247.0) was recorded for the variety 'Fayo' which is a bunch type in its growth habit (Table 2). Higher leaf number produced per plant by the lower plant population density regardless of the varietal and Year difference. With regards to plant density, the highest number of leaves per plant (485.7) was recorded from the lowest plant density (142,857 plants ha^{-1}) while the lowest number of leaves (247.0) was recorded from the highest plant density (333,333 plants ha^{-1}). This might be attributed to difference in growth habit and the lowest number of leaves per plant at the highest plant density might be attributed to more competition for growth resources at higher plant density. The result was in line with that of Kumaga *et al.* (2002) who reported that bambara groundnut (*Vigna subterranea* L) produced greater number of leaves (67.2) at the lower population densities (150,000 plants/ha).

Table 2. Interaction effect of variety and plant density on days to emergence, flowering, maturity and number of leaves per plant of groundnut varieties

Variety	Density (Plants ha^{-1})	Days to emergence	Days to flowering	Days to maturity	number of leaves per plant
Tole-1	142857	9.333 a	44.67 ab	155.0 a	485.7 a
	166,666	9.333 a	44.67 ab	154.0 a	306.3 d
	200,000	9.333 a	37.67 de	150.0 c	300.7 de
	250,000	8.333 abc	38.67 d	150.0 c	281.0 def
	333,333	8.121 b	37.67 de	150.0 c	254.7 ef
Fayo	142857	7.333 cd	44.00 bc	149.7 c	385.0 c
	166,666	7.000 d	44.00 bc	148.5 d	296.7 def
	200,000	8.333 abc	38.33 d	148.3 c	288.7 def
	250,000	7.667 cd	38.00 d	148.3 cd	311.7 d
	333,333	8.000 bcd	36.33 e	147.7 d	247.0 f
Nc-4x	142857	8.333 abc	45.67 a	155.0 a	441.7 ab
	166,666	9.000 ab	44.33 ab	155.0 a	306.3 d
	200,000	8.333 abc	42.67 c	152.0 b	300.7 de
	250,000	9.333 a	38.00 d	150.0 c	281.0 def
	333,333	7.667 cd	37.33 de	150.0 c	254.7 ef
LSD (0.05)		1.0386	2.197	1.988	51.65
CV (%)		10.6	3.3	1.1	13.2

LSD = (0.05) Least Significant Difference at 5% level; CV% = Coefficient of Variation. Means in columns and rows followed by the same letter(s) are not significantly different at 5% level of Significance

3.3.2. Leaf area

The main effects of varieties and plant density on leaf area was highly significant ($P < 0.01$) while the interaction effect of Year, Variety and Plant density was not significant (Appendix Table 1). The highest leaf area (9309 cm^2) was recorded for variety 'Tole-1' with semi-spreading growth habit, while the lowest (7445 cm^2) was for the variety 'Fayo' with bush type growth habit (Table 3). This could be due to the genetically controlled characters of the varieties, since variety 'Tole-1' had the largest leaf number than the two varieties. The highest leaf area (10769 cm^2) was recorded at the plant density of 200,000 (50*10) plant ha^{-1} while the lowest (4834 cm^2) leaf area was at 333333 (30*10). The highest leaf area per plant with in the lower plant density might be due to better availability of growth factors and better penetration of light, consequently increased number of leaves produced at wider row spacing. This is considered as an important character to increase the yield per plant as the vigorous and ample amount of leaves at the early stage of development is crucial to improve the photosynthetic capacity of the crop. This result was in line with the work of Kueneman *et al.* (1978) who reported that the low plant population tended to enhance vegetative growth of dry bean resulting in the development of large leaf area compared to the high and moderate plant populations resulting in sink limitation to photosynthesis.

Table 3: The Main effect of variety and planting density on Leaf area of groundnut:

Treatments	Leaf Area	
Varieties		
Tole-1	9309	a
Fayo	7445	b
NC-4x	7926	b
Significance	**	
LSD (0.05)	681.5	
Planting density ha^{-1}		
142,857(70 cm x 10 cm)	7540	d
166,666(60 cm x 10 cm)	8524	c
200,000(50 cm x 10 cm)	10769	a
250,000(40 cm x 10 cm)	9464	b
333,333(30 cm x 10 cm)	4834	e
Significance	**	
LSD (0.05)	879.8	
CV (%)	16.0	

LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; ** significant at 1%, Means in column followed by the same letters are not significantly different at 1% level of Significance

3.3.3. Leaf area index

The interaction effect of Year and plant density was highly significant (P <0.01) on leaf area index of ground nut whereas, the interaction effect of the three factors was non-significant (Appendix Table 1). According to the analysis of variance, the leaf area index was significantly increased from 2.48 to 4.61 as the plant density increased from 142,857 to 333,333 plants ha-1. Moreover, the highest leaf area index (4.61) was recorded at the highest plant density (333,333 plants ha-1) and lowest leaf area index (2.48) was recorded at the lowest plant density (142,857 plants ha-1)(Table 4). This might be due to the increment of plant population from 142,857 plants ha^{-1} to 333,333 plants ha^{-1} on a fixed area of land. This result agrees with the findings of Mercy (2010) who reported that, the highest leaf area index value (5) was recorded at the highest population density of 100,000 plants ha^{-1} than 50,000 plants ha^{-1} in Bambara groundnut (*Vigna subterranea* L). Moreover, Abdel (2008) also reported that increased plant density increased leaf area index on faba bean.

Table 4. The interaction effect of year and planting density on Leaf area index of groundnut:

Years	Density				
	1	2	3	4	5
1	2.478e	2.733e	3.878bc	4.056b	4.611a
2	3.244d	3.356d	3.578cd	3.878bc	4.522a
LSD(0.05)	0.5148				
CV	12.3				

LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation. Means in column followed by the same letters are not significantly different at 5% level of Significance

3.4. Yield components and yield

3.4.1. Percent death rate

The analysis of variance showed that, the interaction effects of variety and plant density was highly significant (P<0.01) while the interaction effect of the three factors Year, variety and plant density was non-significant on percent death rate at harvest when compared to at thinning (Appendix 1). The highest mortality rate (**13.667**%) was recorded for the variety 'NC-4x' at the highest plant density (333,333 plants ha^{-1} (30cm × 10 cm), while the least mortality (**3.367**%) recorded for the variety Tole-1 at the lowest plant density 142,857 plants/ ha (70 cm × 10 cm) (Table 5). This result could be due to the inherent variation among the varieties in their response to biotic and abiotic stresses and availability of more space at lower plant density might have resulted in less competition for resources and less death recorded in lower densities. In general as the plant density increased, the percent mortality rate also increased. The result was in conformity with the findings of Njoka *et al*. (2002) who reported increased plant mortality rate as density of plant increased in common bean.

3.4.2. Above ground dry biomass yields

The interaction effect of variety and plant density was highly significant (P < 0.01) on the above-ground dry biomass of groundnut while the interaction effect of Year, Variety and plant density found non-significant (Appendix Table 1). The highest above ground dry Biomass was recorded for the variety "Tole-1" at the highest plant density 333,333 plants ha^{-1} (30 cm x 10 cm). While the lowest dry biomass yields (4002kg ha-1) recorded for the variety 'Fayo' at the lowest plant density of 142,857 (70 cm x 10 cm) plants per hectare (Table 5). This might be due to the reason that, at higher plant densities crop growth resources are efficiently used and resulted in higher dry matter accumulation at optimum plant densities. The result was in agreement with the work of Mckenzie *et al.* (1992) who reported that the amount of solar radiation intercepted in to the canopy depends on plant density where the higher plant population density speeds up canopy closure and increases interception of photo-synthetically active radiation (PAR) needed for carbohydrate production and higher biomass in the plants. Bell *et al*. (1987).

3.4.3. Number of pegs per plant

The analysis of variance showed that, the interaction effect of variety and plant density showed a highly significant (P < 0.01) effect on number of pegs per plant (Appendix Table 2). Nevertheless, the interaction effect of the three factors year, variety and plant density was non-significant on this parameter. The highest total number of pegs (**65.83**) was recorded for variety 'Tole-1' at the plant density of 142,857 plants ha^{-1} (70 cm x 10 cm) while, the lowest (**32.83**) number of pegs per plant was recorded for variety 'NC-4x' at density of 333,333 (40cm x 10cm) (Table 5). This might be due to the inherent character of the variety 'Tole-1' which has spreading growth habit and hence produced more number of pegs per plant. In wider inter row spacing the growth factors (nutrient, moisture and light) for individual plants might be easily accessible that retained more flowers and supported the development of lateral branches in the spreading type variety. This might be due to the inherent characters of varieties and higher availability of growth resources at lower plant densities increased number of pegs per plant. Similarly, Kathirvelan and Kalaiselvan, (2007) reported higher number of pegs at lower plant densities of groundnut 148,148 plants ha^{-1} (45cm x 15cm) than at higher plant densities 333,333 plants ha^{-1} (30cm x 10cm) of groundnut.

Table 5. Interaction effect of variety and plant density on percent Death Rate, above round biomass, and number of pegs per plant of groundnut varieties

Variety	Density (Plants ha^{-1})	percent Death Rate	Above round dry biomass	Number of pegs per plant
Tole-1	142857	3.367 h	4854 de	*78.**83*** a

	166,666	3.650 gh	5163 cd	60.50 ab
	200,000	4.283 efg	5472 bc	59.17 abc
	250,000	4.467 ef	5580 bc	57.17abcd
	333,333	7.833 c	6039 a	40.00 ghi
Fayo	142857	3.600 gh	4002 g	60.17 abc
	166,666	3.933 fgh	4600 ef	58.00 abc
	200,000	4.750 de	4942 de	49.67 cdefg
	250,000	5.383 d	5202 cd	41.83 fghi
	333,333	10.000 b	5805 ab	36.17 hi
Nc-4x	142857	3.817 fgh	4299 fg	53.67 bcde
	166,666	4.267 efg	4582 ef	52.33 bcdef
	200,000	5.317 d	4967 de	46.83 defg
	250,000	5.267 d	5169 cd	45.33 efgh
	333,333	13.667 a	6050 a	32.83 i
LSD (0.05)		0.7664	452.6	10.535
CV (%)		11.9	7.7	18

LSD = Least Significant Difference at 5% level; CV= Coefficient of Variation. Means in column and row followed by the same letter (s) are not significantly different at 5% level of significant.

3.4.4. Total pod per plant

According to the analysis of variance, the interaction effect of variety and plant density was highly significant ($P<0.01$) on total number of pods per plant and the interaction effect of the three factors year, variety and plant density found to be non-significant (Appendix Table 2). The highest total number of pods per plant (**77.33**) was obtained for variety 'Tole-1' with semi-spreading growth habit at the plant density of 142857 plants per hectare while the variety 'NC-4x' with bunch type growth habit gave the lowest total number of pod per plant (**28.67**) at the plant density of 333,333 plants ha^{-1} (30×10) (Table 6). The variations in the number of pods observed were probably largely attributable to the genotypes of the groundnut varieties and higher availability of growth resources at lower plant densities. Virk *et al*. (2005) and Abdullah *et al.* (2007) also reported that, increased plant density decreased number of pods per plant and as plant density decreased, number of pods per plant increased. In general, total number of pods per plant was high in plots with the lowest plant densities and low in plots containing highest plant densities per plot. Similarly, increased number of pods per plant with increasing plant spacing observed in this investigation concurs with many researchers in different crops (El Naim *et al.*, 2010b and El Naim and Jabereldar, 2010). They reported that closer spacing reduced the number of pods per plant in cow pea and sesame.

3.4.5. Matured pod per plant

The analysis of variance indicated that, the interaction effect of variety and plant density was highly significant ($P<0.01$) on number of matured pod per plant while the interaction effect of Year, variety and plant density found non-significant at ($P<0.05$) (Appendix Table 2). The highest number of matured pod per plant (**73.00**) was obtained from variety 'Tole-1' planted at the plant population density of 142,857 plants ha^{-1} while the variety 'NC-4x' planted at plant density of 333,333 plants ha^{-1} produced the lowest (24.67) number of matured pods per plant (Table 6) like the trend observed for number of pegs and total pods per plant. These results might be attributed to the competition between plants and between the different parts of the individual plant under high plant population densities. The increase in number of matured pods per plant with decreasing plant density observed in this investigation agreed with the results of El Naim *et al*. (2010) and El Naim and Jabereldar (2010). They reported that closer spacing reduced the number of pods per plant in cowpea (*Vigna unguiculata* L.).

3.4.6. Dry pod yield per hectare

The interaction effect of the variety and plant density on dry pod yield of groundnut was highly significant (P<0.01) effect while the interaction effects of the three factors year, variety and plant density found to be non-significant at (P<0.05) (Appendix Table 2). The variety 'Tole-1' at plant density of 250,000 plants ha^{-1} gave the highest dry pod yield (**3831**kg ha-1) possibly due to the high number of pods per plant with high number of plants per hectare while variety 'Fayo' at plant density of 142,857 plants ha^{-1} gave the lowest dry pod yield (**1702** kg ha^{-1}) (Table 6). This means increasing the plant density lead to increase in dry pod yield ha^{-1} until the optimum plant density was reached and beyond which further increase started to decline in dry pod yield. This might be attributed to the efficient utilization of growth resources and the use of optimum plant densities. Similarly, Annadurai *et al.* (2009) also reported that, closer spacing of peanut at 25cm x 10 cm significantly gave higher pod and haulm yield of 2694 and 4397 kg ha^{-1}, respectively as compared to 30 cm x 10 cm, 20 cm x10 cm and 15 cm x 10 cm spacing. In contrast, increasing plant density to optimum, increased dry pod yield ha^{-1} El Naim *et al.* (2010c) reported supporting evidences. Similarly, Mkadawire and Sibuga (2002) reported high pod yields at population densities of 22 than at 9 plants per m2. Nevertheless, they again reported lower pod yield with increase in plant density up to 66 plants per m^2.

3.4.7. Hundred Seed weight

The analysis of variance revealed that, the interaction effect of variety and plant density on hundred seed weight of groundnut was highly significant (P<0.01) while the interaction effect of Year, Variety and plant density was non-significant (Appendix Table 2). The highest hundred seed weight (86.67gm) was observed for variety 'Tole-1' with semi-spreading growth habit and the lowest (67g) was recorded for variety 'NC-4x' with bunch type growth habit (Table 6). The variation in seed size of groundnut could be due to genetic difference and the result of present investigation was in agreement with earlier investigations on cowpea by Turk *et al.* (1980) who reported that individual seed weight was highly affected by genetic factors except in case of severe water stress and hot desiccating winds causing forced maturity. In general, with increased plant density hundred seed weight decreased, where the highest hundred seed weight (86.67g) was recorded at the lowest plant density of 142,857 plants per ha^{-1} (70 cm × 10 cm) whereas, the lowest (67g) was recorded at the highest plant density of 333, 333 plant ha^{-1} (30 cm × 10 cm) (Table 6). This might be because of the wider spaced plants, that improved the supply of assimilates to be stored in the seed, hence, the weight of hundred seeds increased. The result was in agreement with those obtained by Solomon (2003) on haricot bean, who reported that hundred seed weight decreased with increase in plant density. Moreover, Matthews *et al.* (2008) reported that hundred seed weight of faba bean was negatively related with plant density. In contrast to this result Lemlem (2011), found non-significant effect of plant density on hundred seed weight of soybean.

Table 6. Interaction effect of variety and plant density on total pods per plant, matured pod per plant, Dry pod yield (kg ha^{-1}) and hundred seed weight of groundnut

Variety	Density (Plants ha^{-1})	total pods per plant	matured pods per plant	Dry pod yield (kg ha^{-1})	hundred seed weight
Tole-1	142857	77.33 a	73.00 a	2052 ghi	86.67 a
	166,666	71.00 ab	66.83 ab	2341 efg	84.33 ab
	200,000	67.00 abc	63.50 abc	3346 b	82.67 ab
	250,000	63.67 bc	60.83 bc	3831 a	78.00 bc
	333,333	36.00 gh	32.83 fg	2126 ghi	71.33 de

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Fayo	142857	69.17	ab	64.83	abc	1702	i	78.00	bc
	166,666	65.67	abc	60.00	bc	2073	ghi	74.00	cd
	200,000	49.83	def	45.83	de	3128	bc	74.33	cd
	250,000	38.17	fgh	35.33	efg	2711	cde	70.00	de
	333,333	31.50	h	27.83	g	2033	ghi	67.67	e
Nc-4x	142857	61.17	bcd	58.67	bc	1798	hi	71.33	de
	166,666	56.50	cde	54.17	cd	2590	def	67.33	e
	200,000	49.00	ef	44.17	def	2389	efg	67.00	e
	250,000	47.50	efg	44.33	def	2921	bcd	68.67	de
	333,333	28.67	h	24.67	g	2225	fgh	70.67	de
LSD (0.05)		12.04		11.63		441.5		6.171	
CV (%)		19.2		19.9		15.4		7.2	

LSD = Least Significant Difference at 5% level; CV= Coefficient of Variation. Means in column and row followed by the same letters are not significantly different at 5% level of significance.

3.4.8. Number of seed per pod

The main effect of variety and plant density showed highly significant (P <0.01) effect on number of seed per pod while the interaction effect of all the factors was non- significant on number of seed per pod (Appendix Table 2). Among the varieties, the highest number of seed per pod (3.27) was obtained for the variety 'Tole-1' with semi-spreading growth habit and the lowest number of seed per pod (1.93) was obtained for variety 'NC-4x' with bush type growth habit (Table 7). This might be attributed to number of seed per pod is a varietal difference which is largely controlled by plant genetic factors than agronomic practices. The highest number of seed per pod was recorded at the plant density of 250,000 plants ha^{-1}. On the contrary, the lowest number of seed per pod was recorded at planting density of 333,333 plants $ha^{-1.}$ Similar results were reported by Nadeem *et al.* (2004) who found that planting pattern had not significant effect on the number of seeds per pod in grain legumes. Leitch and Sahi (1999) also reported that the number of pods per plant increased as plant density increased while the number of seeds per pod was influenced to a lesser extent by spacing. Ahmad and Mohammed (2004) also reported that inherent varietal differences in seed number per pod in pigeon pea.

Table 7: Main effects of varieties and planting density on seed/pod of groundnut

Treatments	Seed/Pod	
Varieties		
Tole-1	3.267	a
Fayo	2.500	b
NC-4x	1.933	c
Significance	**	
LSD (0.05)	0.2731	
Planting density ha^{-1}		
142,857(70 cm x 10 cm)	2.778	a
166,666(60 cm x 10 cm)	2.611	ab
200,000(50 cm x 10 cm)	2.333	bc

250,000(40 cm x 10 cm)	2.889	a
333,333(30 cm x 10 cm)	2.222	c
Significance	**	
LSD (0.05)	0.3526	
CV (%)	20.6	

LSD = Least Significant Difference at 5% level; CV= Coefficient of Variation. Means in column and row followed by the same letters are not significantly different at 5% level of significance.

3.4.9. Shelling percentage

Shelling percentage is the indication of pod filling efficiency and high shelling percentage values indicate effective pod filling. In this study, the interaction effect of Year, variety and plant density was non-significant while, the interaction effect of variety and plant density found significant ($P<0.05$) on the shelling percentage ground nut (Appendix Table 2). The highest shelling percentage (78%) was recorded for variety 'Tole-1' at the planting density of 250,000 ha^{-1} (40 x 10) while the lowest (51%) was recorded for variety 'Nc-4x' at the plant density of 333,333 ha^{-1} (30 x 10) (Table 8). This might be due to the difference in variety and efficient partitioning of assimilates into the seed rather than the pod in the higher plant densities and more luxurious growth in the lower plant densities favored more pod formation than seed yield. Chandrasekaran *et al.* (2007) reported significant differences among the groundnut varieties with shelling ranging from 69.0 to 72.7%. Likewise, El Naim *et al.* (2010) reported that plant density had no significant effect on shelling percent in cowpea.

3.4.10. Seed yield per hectare

The interaction effect of variety and plant density were highly significant ($P < 0.01$) on seed yield of groundnut. Whereas, the interaction effect of Year, Variety and Plant density showed non-significant effect on seed yield ha^{-1} of groundnut (Appendix Table 2). The highest seed yield (**2790** kg ha^{-1}) was obtained for variety 'Tole-1' with semi-spreading growth habit at plant density of 250,000 plants ha^{-1} while the lowest seed yield (**980** kg ha^{-1}) was obtained for variety 'Fayo' with bunch type growth habit at plant density of 142,857 plants ha^{-1} (Table 8). The highest seed yield produced by variety 'Tole-1' could be attributed to its more number of seeds per pod, higher number of pods per plant, hundred seed weight and shelling percentage. In general, the higher seed yield at the higher plant densities might be attributed to higher yield potential of the varieties and efficient utilization of growth resources and the lowest seed yield (980 kg ha^{-1}) at the lowest plant density 142,857 plants ha^{-1} might be attributed to the more luxurious growth because of the more resources at the lower plant density initiated more pod thickness than the seed yield. In line with this result, El Naim and Jabereldar (2010), found that seed yield substantially decreased with increasing planting density from 41,667 plants ha-1 (60 cm x40 cm) to 166,667 plants ha-1 (60 cm x10 cm) gave 40% more yield under rain-fed conditions in groundnut. Several researchers have reported higher yield in close spaced (30 cm × 15 cm) compared to wide (50 cm× 10 cm) spaced groundnut systems Ahmad *et al.,* 2007). Higher yields from higher plant densities are mainly attributed to effective utilization of water, nutrients and perhaps more importantly light (Wells *et al.,* 1993).

3.4.11. Harvest index

The interaction effect of variety and plant density was found significant ($P < 0.05$) on the harvest index of groundnut (Appendix Table 2). Among the varieties, the highest harvest index (**36.5%)** was obtained from the variety "Tole-1" at planting density of 250,000 plants ha^{-1} while the lowest harvest index **(15.17%)** was recorded for variety "Fayo" at planting density of 142,857 (70 cm × 10 cm) plants ha^{-1} (Table 8). This could be due to the increase in biological yield as a result of varietal difference with no significant increases in seed yield, and this leads to lower harvest indices. Harvest index increased from 15.17% to 36.5% as the plant population increased from 142,857 (70 cm × 10 cm) to 250,000 (40 cm × 10 cm) plants ha^{-1} and then decreased to (18.67) when plant density increased from 250,000 (40 cm × 10 cm) to 333,333 (30 cm × 10 cm) plants ha^{-1} (Table 8). A decrease in plant density favors huge vegetative growth and thereby results in lower percent of productive pegs, pods, seed per pod and finally lower harvest index when beyond optimum plant density. This could be attributed to the rapid development of seed yield in higher plant density by optimizing utilization of growth factors, once the reproductive phase started, so that the process of maturation proceeds quickly and lead to harvestable crop while weather conditions are good. These results are in agreement with the findings of Mujumdar and Roy (1992) who reported that, higher number of plants per unit area resulted in higher dry matter production, which in turn accounted for higher yield as well as higher harvest index at higher plant density of 333,000 plants per hectare as compared to 166,000 plants per hectare.

Table 8. Interaction effect of variety and plant density on Shelling percentage, Seed yield (kg ha^{-1}) and harvest index (%) of groundnut

Variety	Density (Plants ha^{-1})	Shelling percentage	Seed yield (kg ha^{-1})	Harvest index (%)
Tole-1	142857	65.00 d	1250 ghi	**15.17** g
	166,666	70.00 b	1606 de	24.67 cdef
	200,000	69.83 b	2343 b	33.33 ab
	250,000	**78.00** a	**2790** a	**36.50** a
	333,333	61.00 e	1486 efg	21.33 efg
Fayo	142857	60.00 e	980 i	20.83 efg
	166,666	64.50 d c	1292 fgh	23.83 cdef
	200,000	65.83 d	**2011** c	28.50 bcd
	250,000	69.00 bc	1774 cd	31.50 ab
	333,333	56.00 f	1266 gh	18.83 fg
Nc-4x	142857	56.67 f	1107 hi	22.00 def
	166,666	61.00 e	1672 cde	28.00 bcd
	200,000	66.00 cd	1561 de def	27.00 bcde
	250,000	65.00 d	**1922** c	30.33 abc
	333,333	**51.00** g	1473 efg	18.67 fg4|
LSD (0.05)		3.117	272.8	6.581
CV (%)		4.2	14.5	22.4

LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation, Means in column and rows followed by the same letters are not significantly different at 5% level of significant.

4. SUMMARY AND CONCLUSION

Groundnuts are a valuable source of protein, fat, energy, and minerals and generate cash income to many poor farmers in the developing world. Plant density in a given area greatly determines growth and development of crops particularly the yield components and yield highly affected by plant density and variety. A field experiment was, therefore, conducted during the 2013 and 2015 main rainy seasons (May to October) at the experimental site of Yabello pastoral and dry land Agriculture Research Center at Abeya district, Borana zone, southern Ethiopia to determine the effect of planting density on growth parameters, yield and yield components of groundnut varieties. Experimental treatments consisted of factorial combinations of five levels of planting densities (142,857 (70 cm x 10 cm), 166,666 (60 cm x 10 cm), 200,000 (50 cm x 10 cm), 250,000 (40 cm x 10 cm), 333,333 (30 cm x 10 cm) plants per hectare) and three groundnut varieties (Tole-1, Fayo and NC-4x). The treatments were replicated three times in a randomized complete block design during the three years. The interaction effect of variety and plant density found highly significant on Days to 50% flowering. The variety 'Fayo' flowered early (36.3 days) and variety 'NC-4x' flowered late (45.67 days). Plant density and variety had highly significant effect on days to maturity, where variety 'Fayo matured earlier (147.7days) and variety 'Tole-1' matured late (155.0 days). Days to maturity increased with decreased plant density from 147.7 days at 333,333 plants hectare to 155.0 days at 142,857 plants per hectare. From the varieties under study, the highest (**4.6**) and the lowest (**2.5**) leaf area index were obtained for the variety "Tole-1" in the 1st year and (4.5) and (3.2) was found as maximum and minimum leaf area index in the 2nd year for the variety. Leaf area index found to be maximum (4.6) in plots of 333,333 plants per hectare and lowest (**2.5**) in plots of 142,857 plants per hectare. The main effect of variety and plant density found highly significant on seed per pod and Leaf area of groundnut. In the same manner, highly significant interaction effect of Year and plant density was observed on leaf area index, during the year2013. Both variety and plant density had highly significant effect on days to flower, days to maturity, Number of leaf per plant, leaf area, leaf area index, above ground biomass, death rate percent, number of pegs per plant, total pod per plant, matured pod per plant, dry pod yield, Shelling percentage, seed yield, seed per pod and hundred seed weight respectively. There was a significant interaction effect of variety and plant density on number of leaves per plant, shelling percentage and harvest index of groundnut. Variety 'Tole-1' with semi-spreading growth habit gave the highest seed yield of 2790kg ha^{-1} at a plant density of 250,000 plants ha^{-1} (40 × 10). On the other hand, variety 'Fayo' with bush type growth habit gave the lowest seed yield of 980 kg ha^{-1} at plant density of 142,857 plants ha-1 (70 × 10). Optimizing plant population density is very critical in increasing production and productivity of a crop in a given area. Therefore, the results from the study indicated that variety and plant density had a significant influence on the growth, yield components and yield of groundnut. The optimum plant population density for varieties 'Tole-1' and 'NC-4x' was 250,000 plants ha^{-1} (40 cm × 10 cm), while 200,000 plants ha^{-1} (50 cm × 10 cm) was for the variety 'Fayo'.

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7. APPENDICES

Appendix Table 1. Analysis of variance showing the mean squares of Phenological parameters of Groundnut as affected by planting density and variety

Parameters with	Mean squares

(df)	Dte	Dtf	Dtm	NLpp	LA	LAI	Biom	DR
Block(2)	0.5778	8.933	7.511	18030	13398427	0.5590	2494115	3.73
Year(1)	0.0000	0.000	0.000	0.000	74823	0.6084	897801**	0.784
Var(2)	16.3111**	16.53**	166.58**	64599**	28099165**	1.6223**	2191789**	22.92**
Den(4)	0.3333	225.49**	37.733**	74241**	90294128**	8.7042**	4700859**	142.8**
Year*Var(2)	0.0000	0.000	0.000	0.000	1383	0.0114	794	0.097
Year*Den(4)	0.0000	0.000	0.000	0.000	1372	1.0904	726	0.008
Var*Den(8)	2.5333**	9.089**	24.133**	4705*	3006330	0.2282	953967**	8.31**
Year*ver*Den(8)	0.0000	0.000	0.000	0.000	1357	0.1117	821	0.0772
Error(58)	0.8077	1.807	2.959	1998	1738598	0.1984	153380	0.4398
CV(%)	10.6	3.3	1.1	13.2	16.0	12.3	7.7	11.9

Dte = Days to emergence, Dtf = Days to flowering, Dtm = Days to maturity, NLpp = number of Leaves Per lant, LA = Leaf Area , LAI = Leaf Area Index, Biom = Above ground Biomass and DR = Death Rate.

Appendix Table 2. Analysis of variance showing the mean squares of yield and Yield components of Groundnut as affected by planting density and variety

Parameters with (df)	Mean squares								
	NPPP	TPPP	MPPP	DPY	ShP	SY	SPP	HSW	HI
Block(2)	87.70	447.7	434.3	994160	2.744	435456.	0.23	25.73	9.43
Year(1)	3276.10**	12.1	592.9*	28873	8.100	19478	0. 41	0.19	2160.90**
Var(2)	849.23**	1804.1**	1818.5**	1483433**	601.68**	1692866**	13.43**	1049.2**	17.50
Den(4)	1220.13**	2969.4**	2949.7**	5496239**	594.1**	3162667.**	1.46**	183.60**	620.63**
Year*Var(2)	368.03**	35.0	15.6	2449	0.18	1349	0.31	0.51	0.63
Year*Den(4)	570.79**	19.4	22.9	6641	7.544	10945	0.21	0.25	122.59
Var*Den(8)	198.55**	559.3**	506.4**	701014**	18.53*	371825**	0.32	79.03**	69.11*
Year*ver*Den(8)	122.94	8.5	14.8	3295	0.586	3483	0.31	0.34	27.33
Error(58)	83.09	108.6	101.2	145940	3.117	55712	0.2793	28.51	32.42
CV(%)	18.0	19.2	19.9	15.4	4.2	14.5	20.6	13.0	22.4

NPPP = Number of Pegs per plant, TPPP = Total pod per plant, MPPP = Matured pod per plant, DPY = Dry pod Yield per plot, ShP = SY = Seed Yield, SPP = Seed per pod, HSW = Hundred seed Weight, HI = Harvest Index.

Figure-1: 2013 Abeya climate information (Rain fall, Minimum and Maximum temperature)

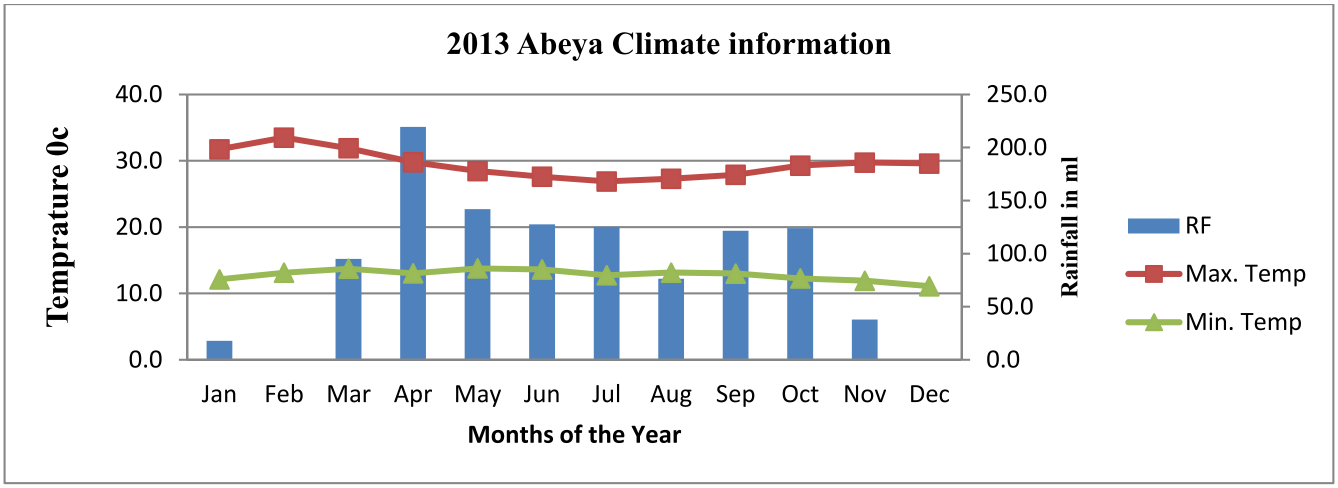

Figure-1: 2015 Abeya climate information (Rain fall, Minimum and Maximum temperature)