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Effect of population, propagule size and nitrogen levels on growth and rhizome yield of ginger (*Zingiber officinale* Rosc.) in Southern Ethiopia

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Abstract

A field experiment was conducted during the 2021 main cropping season to determine the effect of density, rhizome size, and applied nitrogen levels on the growth and rhizome yield of ginger (*Zingiber officinale* Rosc). The treatments consisted of a factorial combination of three population densities, three rhizome sizes, and three nitrogen levels laid out in a randomized complete block design with three replications. The results revealed that plant height, leaf number, leaf area, number of tillers, and number of fingers were significantly affected by the main effects and interaction effects of nitrogen and population density. Rhizome length and yield were significantly influenced by the interaction of rhizome size and nitrogen, whereas days to emergence, days to maturity, plant height, leaf number, and fresh rhizome yield were significantly affected by the 3-way interaction. The establishment of ginger with 40g rhizome size, 166 667 plants ha^{-1} and its nourishment with 100kg N ha^{-1} enhanced its growth and rhizome yield.

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Introduction

Ginger (*Zingiber officinale* Rosc) is the underground rhizome of a perennial tropical crop. Among all spices, ginger is the main cash crop supporting the livelihood and improving the economic level of many people. It is well known in human communities around the world. Ginger can be grown across more diverse conditions than most other spices. It requires a warm and humid climate; it is mainly cultivated in the tropics (Poudel *et al.*, 2015).

Ginger is widely used in food, beverages, confectionery, and medicine. It is nutritionally important as a source of vitamins and minerals in its fresh and dried (powdered) forms. It is known to supply significant levels of calcium, potassium, phosphorus, magnesium, niacin, and vitamin C. (Raghavan, 2007). One hundred grams of dried ginger contain approximately 9.4 grams of proteins, 347 kcal of food energy, 70.8 grams of total carbohydrates, and significant quantities of macro-and micro-nutrients (Vasala, 2001; Valenzuela, 2011). It is valued in medicine as a carminative and stimulant of the gastrointestinal tract. Dry ginger is used for the manufacture of oil, oleoresin, essence, soft drinks, etc. The production of ginger in recent years has been increasing due to the high demand for rhizomes both as a dietary spice and to control of various diseases, including high blood cholesterol levels, high blood pressure, nausea, and insomnia. It is an economically important plant, largely cropped for its variety of uses, especially for its medicinal and flavoring potentials (Schwertner and Rio, 2007). As a result of the increasing consumption of ginger in medicines and foods, it was considered important to assess some of the factors that could boost its production. The productivity of ginger varies across different parts of the world. The area under ginger cultivation in the world was estimated to be 314350 hectares in 2011, with a total production of 2025571 tons; out of which the share of Ethiopia was 7746 tons, that is about 0.38%. In 2006/07, about 2,896372 quintals of fresh ginger were produced from an area of 18,240 hectares of land, indicating the regional average rhizome yield of 160 qt/ha (BoARD, 2008).

The ginger yield on farmers' fields is very low i.e., 15.87 t ha^{-1}, which is far less than the crop's potential (Hailemichael *et al.*, 2008). This is attributed to several factors, of which soil fertility, size of planting material, variety, weed, spacing, population density and weather condition are the most important ones (Lyocks *et al.*, 2013). Among the agronomic practices that affect ginger crop growth and yield are population density, size of planting materials, and nitrogen fertilizers.

Plant population plays an important role in contributing to good growth and high yield; because the dense plant population will not create an opportunity for plants to have a proper light for photosynthesis and may lead to a high level of disease incidences. On the other hand, a very small population will also reduce the expected yield per unit area (Pookpakedi and Patradilok, 1993). Closer spacing might affect the growth and development of plants due to competition among them for nutrients and other resources available per unit area but under spacing above the optimum, the utilization of the land may be less and thereby the yield might have been reduced. Grima and Digafie (2004) were recommended 222,000 plants per hectare (15cm x 30cm spacing) to all areas and locations without considering the type of planting material and different environmental conditions. Propagule sizes have been reported to influence the sprouting rate, early growth, and development of crops like yam, pineapple, and plantain (Lawal *et al.*, 2016). The food reserves provide nutrients and energy required for crops seeds/propagule germination/sprouting and means of sustenance to the plantlets and seedling. The higher and more readily available these growth factors, the better the early crop growth and development. Nutrient management is always an important consideration for ginger because it requires large quantities of nutrients. Nitrogen is one of the most limiting factors for ginger production. Therefore, continuous cultivation of a crop like ginger on the same land will lead to soil mining, degradation of soil quality, and consequent low yield. Therefore, the objective of this study was to determine the effect of population density, propagule size, and different nitrogen fertilizer rates on the growth and rhizome yield of the ginger crop.

Materials and methods

Description of the experimental sites

The study was conducted in Hadero Tunto Zuria *Woreda*, Kembata Tembaro Zone, Southern Nations Nationalities, and People Regional State at Ajore Kebele farmers' training center during the main cropping season of 2021. Astronomically, it is situated between 7°7'30" to 7°19'30" N latitude, 37°34' 30" to37°43'30"E longitude at an altitude of 1300 m - 2600 meters above sea level. The mean annual rainfall ranges from 800mm – 1200mm with a mean annual temperature of 18°C-32°C (Hadero Tunto Zuria *Woreda* Agricultural Office, 2012).

Experimental materials

The experiment was conducted using Volvo cultivar locally known as "Hargema" which is collected from Ajore Kebele farmers. The seed rhizomes were one year old and have two active buds. Different levels of nitrogen fertilizer rates were used and it was applied at the time of planting.

Treatments and experimental design

An experiment with treatments of a factorial combination of three plant populations (333 333, 222 222, and 166 667 plants ha^{-1} based on 30 x 10, 30 x 15, and 30 x 20cm row spacing, respectively), three rhizome sizes (20, 30 and 40g), and three nitrogen levels (0kg ha^{-1} as control, 50kg ha^{-1} and 100kg ha^{-1}) were used. The experiment was laid out in randomized complete block design in 3 x 3 x 3 factorial arrangements with three replications. Each plot size in the experiment was 1.5m x 2m, with 5 rows of 10, 15, and 20cm apart giving a gross plot area of 3 m^2. Spacing of 1m and 0.5m was maintained between adjacent blocks and plots, respectively. All the required data were collected from the middle three rows leaving the outermost rows on both sides and some distance at both ends as a border at each plot of the experiment based on the net harvestable plot area. The net harvestable area was 0.6m x 1.70m, 0.6m x 1.55m and 0.6m x 1.40m for 30 x 10cm, 30 x 15cm and 30 x 20cm row spaced plots.

Experimental procedure

Before planting soil sample was taken from the experimental site according to the appropriate sampling technique and subjected to soil analysis to determine the chemical and physical properties of the soil. The soil sample was taken from 30cm depth of the experimental site by using an auger. While taking the sample zigzag method of soil sampling was implemented. A composite sample of 1kg was prepared from the primary samples through the quartering method. After passing through the proper drying and grinding processes composite sample was submitted to the soil laboratory for the analysis of physical and chemical properties. Total nitrogen, available phosphorus, exchangeable potassium, organic matter, soil pH, and cation exchange capacity, and soil texture are the chemical and physical properties were determined in the laboratory from the sample submitted.

The experimental field was prepared manually before sowing. The ginger cultivar was planted in rows at depth of 8cm. While conducting the experiment all the necessary agronomic practices were carried out accordingly to the recommended for ginger except propagule size, spacing, and the different levels of nitrogen fertilizer rates were studied.

Data collection and measurements

Days to 50% emergence: It was recorded by counting some days from the date of sowing until when 50% of the plants per plot emerged. Days to maturity: Days to physiological maturity were recorded by counting the number of days from the date of sowing until when 90% of the above-ground part of the plant senescent and about 60% dried and when the crop is ready for harvest. Plant height (cm): It was measured from the base of the stem to the tip of the plant from the five randomly sampled plants per plot at maturity time. Leaf number per plant: The average number of leaves per plant was counted from five randomly selected plants in a plot after flowering. Leaf Area (cm^2): Leaf area of five randomly selected plants from the sampling area were determined by using leaf length and width of each leaf and multiplied by leaf area adjustment factor (k= 1.426) (Anteneh, *et al.*, 2008). Leaf area = leaf length x maximum width of leaf x 1.426. Leaf Area Index (LAI): Leaf area index was calculated as the ratio of leaf area to the ground area occupied by the sampled plants**.** LAI = LA/GA. Where: LA is the leaf area of a plant (cm^2) and GA is Ground Area (cm^2). Number of Tillers: Data were collected on the number of tillers/ shoots from the net harvestable plots. Rhizome size (cm): The length of rhizomes was measured from the distal end to the proximal end of those randomly sampled five plants. Number of Fingers per Plant: **-** the number of rhizome fingers from five sampled parent plants was counted. Total Fresh Rhizome Yield (kg): The fresh rhizome yield was obtained from the middle three harvestable rows of each plot and converted into a hectare. It was estimated using the following formula.

$$\text{Total fresh yield per hectare (kg)} = \frac{\text{Yield per three rows (kg) x10 000 (m}^2\text{)}}{\text{Net area of the three rows (m}^2\text{)/ plot}}$$

Statistical data analysis

Data were subjected to analysis of variance (ANOVA) using Gen Stat 15th edition statistical software package. All treatment means were compared using the least significant difference (LSD) test at a 5% level of significance.

Results and discussion

Soil analysis

A composite sample was taken from 0-30cm depth of the experimental site before sowing of the ginger crop and the physicochemical properties of the soil were analyzed at Wolaita Sodo soil laboratory. Based on particle size distribution, the soil contained 54% sand, 15% silt, and 31% clay (Table 1).

Table1. Physico-chemical properties of the topsoil (0 to 30cm) of the experimental sites.

Properties	Contents/ Values	Rating
Soil pH	6.3	Slightly acidic
Organic carbon (%)	1.5	Low
Total nitrogen (%)	0.048	Very low
Available phosphorus (ppm)	8.751	Low
Exchangeable potassium (ppm)	1.58	High
Particle size proportion (%)		
Sand	54	High
Silt	15	Low
Clay	31`	Medium
Soil texture		Sandy clay loam

Hazelton and Murphy (2007) classified soil organic carbon percentages of <1.0, 1.0 – 1.71, 1.72 – 3.0, 3.1 – 4.29, and >4.3 as very low, low, medium, high, and very high, respectively. Similarly, the authors classified soil total nitrogen percentages of < 0.05, 0.05 – 0.15, 0.16 – 0.25, 0.26 – 0.5, and >0.5 as very low, low, medium, high, and very high, respectively. The authors also classified available phosphorus contents of <5, 5 – 10, 11 – 17, 18 – 25, and >25 mg/kg soil as very low, low, medium, high, and very high, respectively. Similarly, they classified exchangeable potassium contents of <0.2, 0.2 – 0.3, 0.4 – 0.7, 0.8 – 2.0, and > 2.0 as very low, low, medium, high, and very high, respectively. Based on this, the organic carbon and available phosphorus were low. Total nitrogen was very low, while exchangeable potassium was high at the experimental site. According to the soil textural class determination triangle, the soil of the experimental site was sandy clay loam which is suitable for ginger production (Miyan *et al.*, 2011).

Days to 50% emergence

The interactive effect of nitrogen level, density, and rhizome size (N x D x RS) was significant on the date of emergence. The largest rhizome size (40g), the density of 333 333 plants $ha^{-1,}$ and application of 100kg N ha^{-1} required shorter days (24.33) to achieve 50% emergence, while the smallest rhizome size (20g), the density of 166 667 plants ha^{-1} and control treatment combination required longer days (40.67) to achieve 50% emergence (Table 2). The sizes of the sett determine the level of emergence and subsequent growth since the process is energy-dependent. The earlier emergence might be attributed due to a relatively greater amount of mobilizable food reserves; because size affects the amount of reserve food that affects the growth rate and vigor of sprouts. However, delayed emergence of the small rhizome size may be due to the depth of planting, low amount of food reserves, and due to lately produced nature small sett sizes may have also longer dormancy. This result is in agreement with the findings of (W/Mariam Woelore *et al.*, 2016) and (Bendell and Daly 1996) who reported that the difference in crop emergence depends on plants sett sizes and those large rhizomes and corms emerged faster (earlier) than smaller. The application of different nitrogen levels had a marked effect on the emergence of ginger. It plays a great role in cell division, multiplication, and growth which lead to fast emergence. The low yield obtained from unfertilized plants when compared with fertilized plants is a pointer to the fact that the application of nitrogen enhanced the growth and development of ginger rhizome. This implied that 40 g contained a sufficient amount of nitrogen which the crop required for fast emergence activities.

Table 2. Interaction effect of density, rhizome size, and nitrogen on days to 50% emergence and days to maturity of ginger.

Density (plants ha^{-1})	Nitrogen (kg N ha^{-1})	Rhizome size (g)					
		Days to 50% emergence			Days to maturity		
		40	30	20	20	30	40
333 333	0	30.00^{b-g}	28.33^{a-e}	35.67^{h}	114.3^{a}	128.3^{bc}	132.0^{bcd}
	50	33.00^{e-h}	30.67^{b-g}	30.67^{b-g}	138.7^{e-h}	145.0^{ij}	141.0^{f-i}
	100	24.33^{a}	30.67^{b-g}	28.67^{a-f}	152.7^{kl}	151.0^{kl}	159.3^{m}
222 222	0	34.33^{gh}	29.00^{b-f}	32.00^{d-h}	126.7^{b}	135.7^{def}	134.0^{cde}
	50	30.67^{b-g}	31.33^{c-h}	30.67^{b-g}	140.7^{f-i}	138.3^{efg}	142.7^{ghi}
	100	26.33^{ab}	32.67^{e-h}	27.33^{a-d}	150.0^{jkl}	149.7^{jk}	153.3^{kl}
166 667	0	31.6^{c-h}	33.33^{fgh}	40.67^{i}	136.0^{def}	132.0^{bcd}	134.0^{cde}
	50	27.00^{abc}	30.00^{b-g}	31.33^{c-h}	139.0^{e-i}	144.0^{g-j}	144.7^{hij}
	100	30.33^{b-g}	29.00^{b-f}	28.33^{a-e}	152.7^{kl}	156.0^{lm}	159.7^{m}
LSD (0.05)		3.94			5.43		
CV (%)		7.8			2.3		

Means followed by the same letter (s) within a column are not significantly different at 5% level of significance

Days to maturity

The main effect of nitrogen fertilizers and 3-way interaction was significant. However, the main effects of density, rhizome size, and interaction of nitrogen and rhizome size (N x RS) and density and rhizome size (PD x RS) were non-significant.

The largest rhizome size (40g), the density of 166 667 plants ha^{-1} and application of 100kg N ha^{-1} delayed days to maturity (159.7) while, the smallest rhizome size (20g), the density of 333 333 plants ha^{-1} and control (0kg N ha^{-1}) enhanced days to maturity (114.3) (Table 2). This might be due to plants treated with an ample amount of nitrogen fertilizer and the largest rhizome size obtained available plant nutrition. However, the enhancement of physiological maturity may be due to an insufficient amount of essential elements under unfertilized treatment and the smallest rhizome size conditions. Densely populated plants might exploit the major growth resources faster by exerting intraspecific competitions which resulted in ginger plants maturing earlier while, sparsely populated plants might have experienced luxurious vegetative growth due to ample growth resources which resulted in delayed maturity. This result disagrees with findings of (W/Mariam Woelore *et al.*, 2016) who reported that days to 90% maturity thus increased with a decrease in sett size of seed rhizome.

Plant height

The main effects of nitrogen and density and their interactions (N x D) and 3-way interaction were significant while, the main effects of rhizome size and their interactions with nitrogen (N x RS) and density (D x RS) were non-significant.

The interactive effect of nitrogen level, density, and rhizome size was significant on plant height (Table 3). Treatment combinations with the largest rhizome size (40g), the density of 333 333 plants ha$^{-1,}$ and application of 100kg N ha^{-1} fertilizer rates gave the tallest plant height (60.67cm) while, the shortest plant height (19.67cm) was obtained from smallest rhizome size (20g), the population density of 166 667 plants ha^{-1} and control treatments.

The possible reason for the maximum plant height might be the early establishment of the crop due to the availability of more food reserves that help growth for large propagule size. An increase in plant height with increasing population density might be due to the competition among plants for the light which could be responsible for the increase in plant height, in which plants become taller due to lower light interception. On the other hand, the shortest plants were obtained in response to the smallest rhizome size, lowest population density, and no application of the nitrogen fertilizer. This may be because nutrients are involved in vital plant functions and contribute to enhanced growth in the height of the plant.

This result agrees with the findings of Misra and Nedunchezs (2004) who reported that the sizes of tuber significantly affected by the plant height.

Table 3. Interaction effect of density, rhizome size, and nitrogen on plant height and number of leaves per plant of the ginger.

Density (plants ha^{-1})	Nitrogen (kg N ha^{-1})	Rhizome size (g)					
		Plant height			Number of leaves per plant		
		20	30	40	20	30	40
333 333	0	21.33^{ab}	22.67^{abc}	25.33^{a-f}	8.67^{a}	11.33^{a-d}	12.00^{a-f}
	50	34.33^{ghi}	34.33^{ghi}	34.67^{ghi}	11.33^{a-d}	12.33^{b-f}	17.00^{gh}
	100	44.00^{j}	36.67^{hij}	60.67^{k}	15.00^{e-h}	18.00^{h}	26.33^{i}
222 222	0	22.67^{abc}	24.00^{a-d}	24.00^{a-d}	11.67^{a-e}	12.33^{b-f}	12.00^{a-f}
	50	25.33^{a-f}	26.67^{a-g}	29.67^{b-h}	14.33^{d-g}	15.33^{fgh}	12.00^{a-f}
	100	34.33^{ghi}	33.00^{e-i}	33.17^{f-i}	14.33^{d-g}	14.33^{d-g}	12.33^{b-f}
166 667	0	19.67^{a}	22.00^{ab}	26.67^{a-g}	10.67^{abc}	9.00^{ab}	12.00^{a-f}
	50	24.33^{a-e}	26.67^{a-g}	28.33^{a-h}	12.00^{a-f}	12.33^{b-f}	12.33^{b-f}
	100	31.33^{c-h}	31.67^{d-h}	40.33^{ij}	14.33^{d-g}	12.33^{b-f}	14.00^{c-g}
LSD (0.05)	7.38					2.94	
CV (%)	14.9					13.4	

Means followed by the same letter (s) within a column are not significantly different at 5% level of significance

Number of leaves per plant

The main effects of nitrogen and density and all interaction effects except nitrogen and rhizome size (N x RS) were significant.

The interactive effect of nitrogen level, density, and rhizome size was significant on the ginger number of leaves. Among the treatment combinations.

The highest number of leaves (26.33) was obtained from plants established with 40g rhizome size, 333 333 plants ha^{-1} and fertilized with 100kg N ha^{-1}, and followed by 30g rhizome size, 333 333 plants ha^{-1} and fertilized with 100kg N ha^{-1}while the least number of leaves (8.67) was obtained from 20g rhizome size, 333 333 plants ha^{-1} and non-fertilized or control treatment (Table 3).

Leaf area

The main effects of nitrogen and density and their interaction effects (N x D) were significant while, the main effects of rhizome size and all interactions except nitrogen and density (N x D) were non-significant.

Interaction of nitrogen fertilizer and density (N x D) was significant on leaf area. The highest value (66.38) and the lowest value (22.53) of leaf area were recorded from the treatment combinations of 100kg N ha^{-1} fertilizer rates coupled with a population density of 333 333 plants ha^{-1} and 0kg N ha^{-1}(control) with 166 667 plants ha^{-1}, respectively (Table 4).

The reasons for the decrease in mean leaf area with a decrease in inter and intra-row spacing might be due to more competition for resources, less light interception per plant that in turn resulted in reduced assimilation rate and limits leaf development. This result disagrees with the findings of (W/Mariam Woelore *et al.*, 2016) who reported that leaf area increased with increased inter and intra-row spacing and reached a maximum at the widest spacing.

Table 4. Interaction effect of density and nitrogen on leaf area, leaf area index, and number of tillers of ginger.

Nitrogen (kg N ha^{-1})	Density (plants ha^{-1})								
	Leaf Area Index			Leaf Area			Number of Tillers		
	333 333	222 222	166 667	333 333	222 222	166 667	333 333	222 222	166 667
0	0.3482^{b}	0.2582^{a}	0.2684^{a}	35.53^{b}	24.01^{a}	22.53^{a}	5.56^{a}	7.11^{ab}	7.89^{b}
50	0.4297^{c}	0.4439^{c}	0.4669^{c}	43.84^{c}	41.28^{bc}	39.21^{bc}	10.89^{c}	12.11^{c}	13.00^{c}
100	0.6507^{e}	0.5420^{d}	0.5418^{d}	66.38^{e}	50.40^{d}	45.52^{cd}	12.67^{c}	15.94^{d}	20.44^{e}
LSD (0.05)		0.0647			5.98			1.99	
CV (%)		15.7			15.5			18.0	

Means followed by the same letter (s) within a column are not significantly different at 5% level of significance

Leaf area index

Leaf area index was significantly affected by the main effects of nitrogen fertilizer rate. All the interactions except nitrogen and density (N x D) were non-significant.

Analysis of variance showed significant differences among the treatment combination on leaf area index. The leaf area index was highest in 100kg N ha^{-1} fertilizer rates coupled with a density of 333 333 plants ha^{-1} and lowest in control with 222 222 plants ha^{-1} (Table 4). The highest value of leaf area index in the highest population density may be due to the presence of a large number of plants per unit area as compared to the lowest plant population.

An increase in leaf area index with increasing population density is associated with an effective light interception and may thus allow high plant populations to attain greater photosynthetic output per unit area. This study is in agreement with the findings of Loss *et al.* (1998) who reported that high population density resulted in significantly earlier canopy closure, larger green leaf area index, and providing larger surface area for more solar radiation interception resulting in high net photosynthesis, more dry matter accumulation during the early vegetative growth, and greater yield than treatments where a low plant density.

Number of tillers

Several tillers were significantly affected by the main effects of nitrogen fertilizer rate and density. All the interactions except nitrogen and density (N x D) were non-significant. Interaction of nitrogen fertilizer and density (N x D) was significant on several tillers.

The highest (20.44) and the lowest (5.56) number of tillers were recorded from the treatment combinations of 100kg N ha^{-1} fertilizer rates coupled with a population density of 166 667 plants ha^{-1} and 0kg N ha^{-1}(control) with 333 333 plants ha^{-1}, respectively (Table 4).

High tillering in the interaction of low plant population density and appropriate fertilizer rates might result from more space and low interplant competition for growth resources. The decrease in the number of tillers with increasing plant population density per unit area may be due to the shortage of growth resources to develop productive tillers rather than mother plants.

Rhizome length

The main effect of nitrogen fertilizer and interaction of nitrogen and rhizome size (N x RS) were significant. However, the main effects of density, rhizome size, the interaction of nitrogen and density (N x D), density and rhizome size (D x RS), and 3-way interaction were non-significant.

The interaction effects of nitrogen fertilizer rate and rhizome size were significant on rhizome length. Interaction of (40g) rhizome size with 50kg N ha^{-1} fertilizer application scored tallest rhizome length (13.67) followed by 20 g x 50kg N ha^{-1} while, control treatment (0kg N ha^{-1}) coupled with rhizome size (20g) scored shortest rhizome length (9.86) (Table 5). The main reason for the increase in rhizome length might be associated with propagule size that accumulated reserve foods, which enable plants to have proper growth and later on made them produce an appropriate length of the rhizome.

Table 5. Interaction effect of rhizome size and nitrogen on rhizome length of ginger.

Nitrogen (kg N ha^{-1})	Rhizome size (g)		
	20	30	40
0	9.86^{a}	12.17^{bc}	10.92^{ab}
50	13.58^{c}	11.44^{abc}	13.67^{c}
100	13.25^{c}	13.17^{c}	13.06^{bc}
LSD (0.05)	2.012		
CV (%)	17.3		

Means followed by the same letter (s) within a column are not significantly different at 5% level of significance

Number of fingers per plant

The main effects of nitrogen and density and their interaction effects (N x D) were significant while, the main effects of rhizome size and all interactions except nitrogen and population density (N x D) were non-significant.

Interaction of nitrogen fertilizer and population density was significant on the number of fingers per plant. Treatment combinations with the application of 100kg N ha^{-1} fertilizer and population density of 166 667 plants ha^{-1} scored higher mean rhizome finger per plant (19.00) while, control treatment (0kg N ha^{-1} coupled with the spacing of 30 x 10cm or population density of 333 333 plants ha^{-1} scored significantly low mean rhizome fingers per plant (8.78) (Table 6).

Table 6. Interaction effect of density and nitrogen on number of fingers of ginger.

Nitrogen (kg N ha^{-1})	Density (plants ha^{-1})		
	333 333	222 222	166 667
0	8.78^{a}	11.11^{ab}	14.00^{cd}
50	14.89^{cd}	16.67^{de}	16.33^{de}
100	12.67^{bc}	14.11^{cd}	19.00^{e}
LSD (0.05)		2.65	
CV (%)		19.9	

Means followed by the same letter (s) within a column are not significantly different at 5% level of significance

The increased number of fingers per plant might be due to an adequate supply of macro-nutrients with the application of nitrogen fertilizer and with an available spacing of the rhizome to produce fingers and reduced competition among the neighboring plants due to the increasing free spacing per plant. This result agrees with the findings of W/Mariam Woelore *et al.*, 2016 who reported that the increasing inter and intra-row spacing, increases the number of fingers per plant in ginger and increases in cloves number per bulb, respectively.

Total fresh rhizome yield

The main effect of nitrogen fertilizer rate, the interaction of nitrogen and rhizome size (N x RS), and the 3-way interaction were significant. However, the main effects of population density, rhizome size, and interaction of nitrogen and density (N x D) and nitrogen and rhizome size (N x RS) were non-significant. Interaction of nitrogen fertilizer rate, population density, and rhizome size was significant on total fresh rhizome yield. Treatment combinations with the largest rhizome size (40g), the population density of 166 667 plants ha$^{-1,}$ and application of 100kg N ha^{-1} fertilizer rates gave higher rhizome fresh yield (14985.7kg ha^{-1}) while, lower rhizome fresh yield per hectare (2095.1kg ha^{-1}) was obtained from smallest rhizome size (20g), the population density of 333 333 plants ha^{-1} and control treatments (Table 7).

Table 7. Interaction effect of density, rhizome size, and nitrogen on total fresh rhizome yield of ginger.

Density (plants ha^{-1})	Nitrogen (kg N ha^{-1})	Rhizome size (g)		
		20	30	40
333 333	0	2095.1^{a}	5244.1^{a-d}	5378.4^{a-d}
	50	8446.1^{def}	6258.8^{b-f}	8892.2^{def}
	100	5865.7^{b-e}	9560.8^{fg}	9150^{ef}
222 222	0	6376.3^{b-e}	6437.6^{b-e}	5140.9^{abc}
	50	7519.4^{b-f}	5241.9^{abc}	7117.2^{b-f}
	100	8109.7^{c-f}	6250.5^{b-e}	4152.7^{abc}
166 667	0	3902.4^{ab}	5101.2^{abc}	7691.7^{b-f}
	50	7483.3^{b-f}	6515.5^{a-d}	8952.4^{c-f}
	100	7833.3^{b-f}	4227.4^{ab}	14985.7^{g}
LSD (0.05)			307.5	
CV (%)			29.7	

Means followed by the same letter (s) within a column are not significantly different at 5% level of significance

The increased total fresh rhizome yield might be due to an adequate supply of the essential nitrogen nutrients, bigger seed pieces, and optimum plant population. Nitrogen fertilizer might be involved in vital plant functions to increase yield and yieldrelated traits. The increase in total fresh rhizome yield at low densities might be due to the availability of more resources for a comparatively less number of plants that they utilized efficiently. Larger rhizome size attained more reserve food that leads to early canopy closure, maximum leaf area, and leaf area index that enhance the production of the bigger weight of rhizomes, it produces a vigorous initial growth of organs due to its available food reserves and an advantage that was maintained through the growing season and that lead to final higher rhizome yield.

Table 8. ANOVA tables for date of 50% emergence, days to maturity, plant height, and leaf number.

Source of variation	d.f.	Mean Squares			
		Date of emergence	Days to maturity	Plant height	Leaf number
Replications	2	10.333	67.60	94.11	55.753
Density (D)	2	8.481^{NS}	120.75^{NS}	428.54^{**}	40.938^{*}
Rhizome Size (RS)	2	12.926^{NS}	211.90^{NS}	228.35^{NS}	26.901^{NS}
Nitrogen (N)	2	246.259^{**}	3678.16^{**}	1577.41^{**}	149.716^{**}
D x RS	4	12.685^{NS}	23.07^{NS}	43.16^{NS}	46.235^{*}
D x N	4	1.741^{NS}	85.27^{**}	133.94^{**}	39.994^{**}
RS x N	4	14.130^{NS}	33.03^{NS}	60.17^{NS}	2.679^{NS}
D x RS x N	8	17.639^{**}	48.50^{**}	44.45^{*}	9.068^{*}
Error	52	5.782	10.99	20.31	3.227

NS = non-significant, d f. = degree of freedom, * and ** = significant at 5% and 1% level of significance, respectively.

Table 9. ANOVA tables for leaf area index, leaf area, number of tillers, and rhizome length.

Source of variation	d.f.	Mean Squares			
		Leaf area index	Leaf area	Number of tillers	Rhizome length
Replications	2	0.004089	36.08	9.318	1.123
Density (D)	2	0.029022^{NS}	1227.57^{**}	112.040^{**}	11.505^{NS}
Rhizome Size (RS)	2	0.003518^{NS}	29.39^{NS}	24.262^{NS}	0.820^{NS}
Nitrogen (N)	2	0.555407^{**}	4832.11^{**}	610.614^{**}	38.140^{**}
D x RS	4	0.004001^{NS}	33.17^{NS}	7.762^{NS}	6.480^{NS}
D x N	4	0.015752^{*}	173.89^{**}	24.003^{**}	11.226^{NS}
RS x N	4	0.006327^{NS}	57.06^{NS}	7.336^{NS}	12.767^{*}
D x RS x N	8	0.005139^{NS}	45.70^{NS}	5.309^{NS}	6.062^{NS}
Error	52	0.004652	39.29	3.119	3.428

NS = non-significant, d f. = degree of freedom; *, ** = significant at 5% and 1% level of significance, respectively.

Table 10. ANOVA tables for the number of fingers per plant and total fresh rhizome yield.

Source of variation	d.f.	Mean Squares	
		Number of fingers per plant	Total fresh rhizome yield
Replications	2	9.910	158821
Density (D)	2	127.642^{**}	80214^{NS}
Rhizome Size (RS)	2	2.297^{NS}	199839^{NS}
Nitrogen (N)	2	170.901^{**}	440625^{**}
D x RS	4	16.818^{NS}	246319^{*}
D x N	4	20.568^{*}	105178^{NS}
RS x N	4	12.987^{NS}	63786^{NS}
D x RS x N	8	11.900^{NS}	94394^{**}
Error	52	6.476	35223

NS = non-significant, d f. = degree of freedom; *, ** = significant at 5% and 1% level of significance, respectively.

The result of the study is consistent with the findings of (W/Mariam Woelore *et al.*, 2016) who reported that the bigger the sett size, the more is the dry matter accumulation with high economic yield harvest and increasing inter and intra-row spacing, increases mean rhizome fresh yield per plant. This existence of significant N x PD x RS interaction indicates that the need for appropriate nitrogen fertilizer rates, plant population density, and rhizome size to achieve a maximum rhizome yield.

Conclusions and recommendation

The results of the study showed that plant height; the number of leaves per plant, leaf area, number of tillers, and number of fingers per plant was significantly affected by the main and their interaction effects of nitrogen and density. In addition, rhizome length and fresh rhizome yield were significantly influenced by the interaction of rhizome size and nitrogen, while days to emergence, days to maturity, plant height, leaf number, and fresh rhizome yield were significantly affected by 3-way interaction. The maximum values of many tillers, fingers per plant, and fresh rhizomes yield were obtained from 40g rhizome size, 166 667 plants ha^{-1} and 100kg N ha^{-1}fertilizer interactions. Therefore, it is advisable to use 40g rhizome size, 166 667 plants ha^{-1} and application of 100kg N ha^{-1} for optimum production of ginger in the study area. However, further studies should be conducted to come up with site-specific recommendations.

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Disclosure statement

The authors have no potential conflicts of interest

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