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Research Article

Boosting Chickpea Production by Optimizing Inter-Row and Intrarow Spacing at Central Highlands of Ethiopia

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A field experiment was conducted to determine optimum inter-row and intrarow spacing for a higher and economic yield of different chickpea varieties during 2016–2017 cropping season at Debre Zeit and Minjar. The experiment was carried out in a split-plot design replicated three times. The two varieties (Habru and Arerti) were assigned as a main plot and factorial of three inter-row spacing (20 cm, 30 cm, and 40 cm) and three intrarow spacing (5, 10, and 15 cm) as subplot treatments. The result indicated that variety and inter-row and intrarow spacing had a significant effect on yield and yield components of chickpea at both locations. Habru variety gave higher seed and biomass yield than Arerti. The highest seed and biomass yield were recorded for the intrarow and inter-row spacing range of 5–15 × 30–40 cm, respectively. Results of the partial budget analysis showed that the highest net benefit with acceptable marginal rate of return (>100%) was obtained from 10 cm × 30 cm intrarow and inter-row spacing. Therefore, 10 cm × 30 cm intrarow and inter-row spacing (330, 000 plants ha^{-1}) can be recommended for a higher and economically optimum yield of chickpea at central highlands of Ethiopia.

1. Introduction

Chickpea is among the most significant cool-season grain legume crops grown in Ethiopia, which is largely grown in the northern, eastern, and central highlands, where the average annual rainfall is 700–2000 mm and the altitude ranges from 1400 to 2300 m.a.s.l [1]. Chickpea is the foremost legume in the highlands of Vertisols, and the straw is used for livestock feed. It is used for dietary purposes by rural people and poor parts of the urban population [2]. Chickpeas are exported to Asia and Europe, adding to the country's foreign exchange earnings, and are also sold in the local market for a higher price [3]. Moreover, chickpea improves and maintains soil fertility through biological nitrogen fixation. Besides, it can amend the soil and improve the accessibility of macronutrients like potassium (K) and phosphorus (P), especially in acidic soils where P fixation is evident [4]. Despite high potential uses and export claim, the national average yield (2 t ha^{-1}) is far below the potential yield (4 t ha^{-1}) indicating the need to improve optimum crop management practices [5]. The main reasons for the observed yield gap are use of local or low-yielding cultivars, disease and pests, and adoption of poor agronomic management practices such as inappropriate plant density, planting date, and poor drainage system.

Among these factors, planting density is an important factor in which inter-row and intrarow spacing plays an important role, which also influences plant development and grain yield [6]. Several researchers reported the influence of plant density on the seed yield and agronomic features of chickpea. Agegnehu et al. [7] reported a significant effect of plant densities on seed yield of chickpea and the highest seed yield was recorded at a higher planting density/seed rate (24 plants m^{-2}). Likewise, Shiferaw et al. [8] and Agajie [3] demonstrated that chickpea varieties seeded at higher plant densities (50 plants m^{-2} and 33 plants m^{-2}) or (10 cm × 20 cm, and 10 cm × 30 cm intrarow and inter-row spacing) gave the highest seed yield, respectively. Contrary

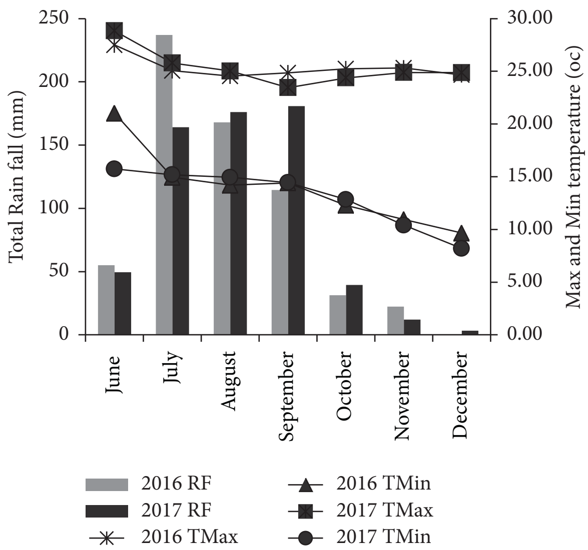

Figure 1: Total rainfall and minimum and maximum temperature from June to December (2016–2017) at Debre Zeit.

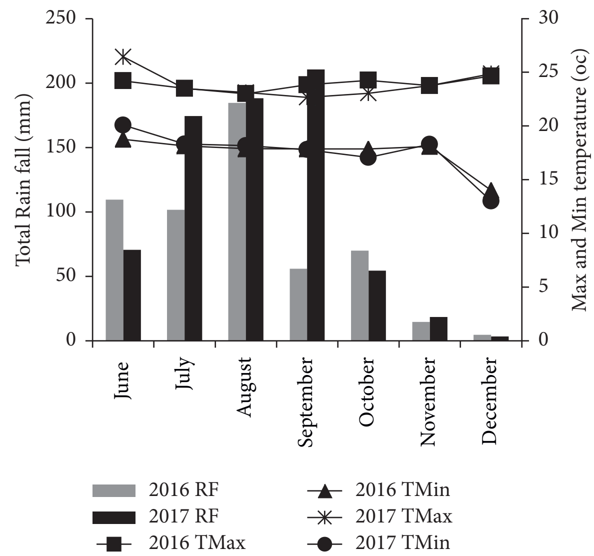

Figure 2: Total rainfall and minimum and maximum temperature from June to December (2016–2017) at Minjar.

to those studies, Bejiga et al. [9] and Eshete [10] reported no significant effect of seed rate ($80\,kg\,ha^{-1}$ to $140\,kg\,ha^{-1}$) on the seed yield of chickpea. All the above-mentioned recommendations did not consider morphological differences amongst the popular varieties that significantly govern plant density. Plant population density is the most flexible agronomic management tool and can be controlled by the producer, depending on the seeding date, seeding conditions, and the expected canopy growth. Studies have shown that chickpea cultivars have different leaf types (fern and unifoliate) and growth habits (erect and branching) [11]. The more branched growth habits may have earlier and greater canopy closure than the erect growth habit; and this may result in differences in plant population density required for optimum yield [12]. In the study areas, both erect and branching growth habits of chickpea varieties have been widely grown, but the farmers use the same seed rate or plant density for all chickpea varieties.

To maximize the yield of chickpea at different agroecologies, it is essential to established site-specific recommendations for adjusting the spatial distribution of the plant population in order to get maximum yield. Optimum plant density of crop cultivars at one site may not apply to other sites because of variation in soil types and other environmental conditions. For instance, Mekuanint et al. [13] found 500,000 plants ha^{-1} in Leptosols and Agajie [3] found 330,000 plans ha^{-1} in Nitosols. Therefore, plant density/seed rate of chickpea needs to consider the growth habit of a given cultivar, as well as soil types, in order to determine optimum plant density that can optimize chickpea yield and ensure efficient use of resources. However, research recommendation for plant population based on-site/soil type and growth habits of varieties is lacking in enhancing the productivity of chickpea in central Ethiopia. The aim of this study was to determine the best intrarow and inter-row spacing for higher and more profitable yields of various chickpea varieties in Ethiopia's central highlands.

Table 1: Soil physiochemical properties of the experimental sites.

	Debre Zeit		Minjar	
	2016	2017	2016	2017
Clay (%)	58.6	58.3	55.1	55.7
Silt (%)	29.3	29.3	30.6	29.7
Sand (%)	12.1	13.4	14.3	14.6
pH (1 : 2.5 H_2O)	6.78	6.91	7.31	7.5
CEC (Cmol (+) kg^{-1} soil)	50.7	49.0	47.2	46.0
Organic matter (%)	1.07	0.84	1.15	1.27
Total N (%)	0.092	0.092	0.097	0.097
Available phosphorus (mg/kg)	12.5	13.24	13.14	12.89

2. Materials and Methods

2.1. Experimental Site. The experiment was conducted in 2016 and 2017 cropping seasons at Minjar Shenkora, North Shewa Zone of Amhara Region and Debre Zeit, East Shewa zone of Oromia region, Ethiopia. Minjar is located at a latitude of 9° 09′ 60.00″ N, longitude of 39° 19′ 60.00″ E, and altitude of 1040 m from the sea level. While Debre Zeit is located in 8°44′ N latitude, 38°58′ E longitude, and altitude of 1,900 m from the sea level. Monthly rainfall for the cropping season and average minimum and maximum temperature during 2016 and 2017 at Debre Zeit and Minjar are presented in Figures 1 and 2, respectively. The preliminary soil analysis of the experimental field (0–30 cm depth) at Debre Zeit and Minjar is presented in Table 1. According to the analysis, the texture of the experimental soils was dominated by the clay fraction and the soil reaction (pH) was close to neutral at both sites. Since the soil of the experimental site was Vertisol, its organic matter (OM) content was low. Likewise, total N and available P were low, indicating being not ideal for crop growth unless fertilizer is applied.

Table 2: Inter-row and intrarow spacing with corresponding plant populations.

Inter-row spacing (cm)	Intrarow spacing		
	5 cm	10 cm	15 cm
20	1,000,000	500,000	330,000
30	670,000	330,000	220,000
40	500,000	250,000	170,000

2.2. Experimental Design and Crop Management. The experiment was carried out in split-plot design with three replications. The two varieties of different growth habit; namely, Habru (branchy type) and Arerti (erect type) were assigned as main plot treatment and factorial of three inter-row spacings (20 cm, 30 cm, and 40 cm) and three intrarow spacings (5 cm, 10 cm, and 15 cm) as subplot treatments. Chickpea varieties of Arerti and Habru were released by Debre Zeit Agricultural Research Centre. The plant population in each spacing combination treatment is presented in Table 2. The subplot size of $3\,m \times 3\,m = 9\,m^2$ was used. Spacing between subplots was 50 cm and between blocks was 1 m.

At Debre Zeit, the fields were ploughed to a fine tilth with a tractor, while at Minjar, oxen were used. The seeds were sown manually by placing two seeds per hill on 5 and 7 August, 2016 and 2017, respectively at Debre Zeit and Minjar. After 10 days of emergence, thinning was done to preserve the suggested intrarow populations. At planting, a recommended rate of 18 kg ha^{-1} of N and 46 kg ha^{-1} of P_2O_5 in the form of DAP (diammonium phosphate) was applied to all subplots based on the results of the initial soil analysis (Table 1) and crop nutrients (N and P) requirements. During the growth cycle, all agronomic practices were carried out according to the crop's recommendations. Pesticide application and manual weeding were used to keep plots free of pests and weeds on a regular basis. The crop was manually harvested at physiological maturity from a net plot area for each plot.

2.3. Data Collection and Measurements. Days to physiological maturity (DPM) was measured as the number of days from the date of planting to the time when about 90% of the plants in a plot had their pods on the lower part become black and the upper part of the plant turned to yellow. Plant height (cm) was measured from the ground to the apex of the plant at the maturity stage. The number of branches per plant was recorded by counting the number of emerging branches from the main stem. The number of pods per plant was counted by picking 10 random plants. Seed yield per plant (g) was determined as the total weight of harvested seeds from 10 randomly selected plants. Thousands of seed weights were calculated using the weight of 1000 randomly selected seeds from the total plot area (g). Biomass yield (kg ha^{-1}) was determined by considering the total harvested crop containing the seeds from the total plot area after three days of sun drying. After threshing the seeds harvested from each plot, the seed yield (kg ha^{-1}) was calculated. The grain yield was adjusted to a moisture content of 12.5% on wet bases, and the moisture content was measured with a moisture tester. The ratio of seed yield to aboveground biomass was used to determine the harvest index.

2.4. Soil Analysis. Initial composite soil samples of 0–30 cm soil depth were taken from 10 random locations in the experimental sites prior to planting. At Debre Zeite Agricultural Research Centre soil laboratory, the samples were tested for physiochemical properties such as soil pH, textural analysis (percentage of sand, silt, and clay), total nitrogen, available phosphorus, organic matter content, and cation exchange capacity (CEC). The pH of the soil was determined using a glass electrode pH meter in a 1 : 2.5 soil to water ratio [14], and the CEC was determined using the ammonium acetate method (NH_4OAC), which involved saturating the soil with 1N NH_4OAC and displacing it with 1N K_2SO_4 [15]. Dry combustion or the Dumas Method was used to determine the organic carbon content and total nitrogen of the soil [16]. The Bray-II method [17] was used to analyse available phosphorus, which was measured using an autoanalyser (Lachat Instruments, WI, USA). Soil texture was determined by the pipette method [18].

2.5. Statistical Analysis. Data were analysed using PROC MIXED of SAS statistical package version 9.4 (SAS Inc., Cary, NC) following the procedure set by Littell et al. [19]. Variety and inter-row and intrarow spacing, along with site-year combinations (4 environments), were considered as fixed effects, while replicates were considered as random effect. Interactions of fixed effects were considered fixed, while any interaction with a random term was considered random. For site-year, variety, and spacing, means were compared using Fisher's Protected LSD test. All differences were deemed significant at $P < 0.05$.

2.6. Economic Analysis. Economic analysis was conducted to assess the feasibility of the treatments using partial and marginal budget analysis [20]. The average yield was reduced by 10% to account for differences between the yields obtained in the research area and the expected yield obtained by farmers using the same treatment. The chickpea seed market price (Ethiopian Birr (ETB) 35 kg^{-1}) was used. However, other costs like fertilizers, labors, and pesticides are considered to be constant for all treatments, since the farmers in the area use family labour for seeding as well as for weeding.

3. Results and Discussion

3.1. Physiological Maturity. Site-year, variety, and spacing had a significant ($P < 0.05$) effect on the physiological maturity of chickpea (Table 3). However, interaction effect of variety and spacing was not significant ($P > 0.05$). Chickpea matured 7 days earlier in 2017 as compared to 2016 at both locations. This might be due to the early termination of rain fall in 2017, which might have forced the crop to mature

Table 3: *P* value from the analysis of variance for the effect of site year, variety, and spacing on phenology, growth, yield, and yield components of chickpea, replications, and their interactions with fixed effects considered as random effects.

		Mean square									
Source	DF	Maturity (days)	Height (cm)	Branching (branch plant^{-1})	Pods plant^{-1}	Seed weight (g 1000 seeds^{-1})	Seed yield plant^{-1} (g)	Seeds m^{-2} (g)	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	Harvest index
Site year	3	<0.0001	<0.0001	0.033	0.0161	0.016	0.0159	0.0004	<0.0001	<0.0001	0.0673
Variety	1	0.0344	0.0004	0.0361	0.0018	0.0019	0.0011	0.0224	0.3155	0.0001	0.1308
Site year ∗ variety	3	0.3672	0.5775	0.8954	0.0491	0.0597	0.4991	0.1684	0.7356	0.5277	0.6734
Spacing	8	<0.0001	<0.0001	<0.0001	0.0068	0.0068	0.0025	<0.0001	0.01476	<0.0001	0.5843
Site year ∗ spacing	24	0.7209	0.496	0.4862	0.4067	0.0601	0.0409	0.0465	0.1015	0.0378	0.0955
Variety ∗ spacing	8	0.0963	0.5922	0.4467	0.5214	0.0524	0.0404	0.0673	0.0217	0.0243	0.7499
Site year ∗ variety ∗ spacing	24	0.5016	0.3952	0.0525	0.3821	0.3909	0.3926	0.404	0.4815	0.5314	0.0892
Residual	64										

Table 4: Phonology, growth parameters, yield and yield components of chickpea as influenced by site year, variety, and inter-row and intrarow spacing.

Treatments	Maturity (days)	Height (cm)	Branching (branch plant^{-1})	Pods plant^{-1}	Seed weight (g 1000 seeds^{-1})	Seed yield plant^{-1} (g)	Seeds m^{-2} (g)	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	Harvest index
Site-year										
Debre Zeit, 2016	104.1a	41.5c	15.8b	37.8c	368.5ab	45.20a	238.4b	2384b	16963b	0.14
Debre Zeit, 2017	97.2b	53.2a	22.8a	44.6b	387.2a	39.07b	264.5a	2645a	17667a	0.15
Minjar, 2016	104.0a	54.9a	21.1a	58.2a	389.2a	46.6a	265.4a	2654a	17667a	0.15
Minjar, 2017	97.2b	49.5b	18.3ab	42.3b	353.0b	40.1b	238.4b	2384b	15963b	0.15
Variety										
Arerti	101.9a	51.2a	21.5a	43.3b	416.2a	41.05b	221.7b	2216.3b	16976b	0.13
Habru	99.3b	48.5b	17.6b	48.2a	332.7b	44.42a	276.4a	2764.2a	18383a	0.15
Intrarow and inter-row spacing										
5 cm × 20 cm	104.5a	58.2a	16.2c	40.4c	340.0b	33.7c	246.6abc	2466abc	17731abc	0.14
10 cm × 20 cm	101.1bc	50.6bc	18.3bc	40.9c	379.3ab	42.4bc	244.2abc	2441abc	18391a	0.13
15 cm × 20 cm	101.7ab	49.4bc	21.4ab	47.4bc	379.7ab	45.7ab	196.9c	1970c	17516ab	0.11
5 cm × 30 cm	102.2ab	51.5b	18.2bc	43.5bc	379.3ab	41.3bc	254.2abc	2542abc	17458bc	0.15
10 cm × 30 cm	101.6ab	47.5bc	18.4bc	41.9bc	372.8ab	42.6bc	292.6a	2926a	18283a	0.16
15 cm × 30 cm	100.0bc	49.1bc	21.9ab	48.0b	383.8ab	44.8ab	257.3abc	2573abc	17224abc	0.15
5 cm × 40 cm	100.6bc	48.4bc	18.1bc	44.4bc	370.1ab	39.5bc	269.5ab	2695abc	17331ab	0.16
10 cm × 40 cm	98.0 cd	48.2bc	19.3bc	46.1bc	357.3ab	42.4bc	265.7ab	2656ab	17982ab	0.15
15 cm × 40 cm	96.0d	45.9c	23.6a	58.9a	408.0a	52.3a	214.4bc	2144bc	12198c	0.18
CV (%)	3.78	8.33	27.7	23	10.86	25.15	17.5	19.5	8.95	1.04

Means followed by the same letter(s) within a column for a given treatment are not significantly different at 5% *P* level.

earlier (Figures 1 and 2). Habru variety matured earlier by 2 days than Arerti variety (Table 4). The difference of maturity nature of the varieties was attributed to their genetic character. The result is in agreement with Mekuanint et al. [13], who reported maturity difference in chickpea varieties. Gonzales and Gonzales [21] also reported significant differences regarding the DPM of chickpea varieties when grown under different environmental conditions. However, Shumi et al. [22] found no significant difference in days of maturity between Arerti and Habru varieties.

Plants were grown in wider spacing (15 cm intrarow and 20 cm inter-row spacing) matured earlier than the rest of the spacing (Table 4). In contrast, the narrowest spacing or highest plant density (100 plants m^{-2}) was found to delay the time needed for maturity. This effect can be due to the fact that the crop growth rate increased as plant density increased [23]. This result is in line with Agajie [3] who reported prolonged maturity of chickpea in narrower intrarow spacing due to high competition for existing resources in the soil, low light interception, and poor air circulation in the canopy. Similarly, Gezahegn et al. [24] found longer physiological maturity of faba bean at narrower spacing. Abeje [25] also reported that soybean planted at narrower inter-row and intrarow spacing (40 cm × 5 cm) matured earlier than wider spacing (80 cm × 15 cm).

3.2. Growth Parameters. The plant height and number of branches per plant of chickpea were significantly ($P < 0.05$) affected by site-year, variety, and spacing, but not by interaction effect of variety and spacing (Table 3). The higher plant height and number of branches per plant were recorded at Debre Zeit during 2017, but was not significantly different from number of branches per plant obtained at Minjar in 2017. In contrast, the lowest plant height and number of branches per plant were obtained at Debre Zeit, 2016. Variation of total rainfall and its distribution in the cropping seasons was responsible for the differences of growth traits in chickpea at each location (Figures 1 and 2). Arerti chickpea variety gave higher plant height and number of branches per plant than Habru variety (Table 4). Genetic variation of chickpea varieties and adaptability to soil and climatic conditions was attributed to the difference of growth between the two chickpea varieties. This result is in agreement with Goa and Ashamo [26], who reported a significant difference between chickpea varieties on plant height. Goa [27] also found a significant performance difference in Habru and Arerti varieties.

Plant height is an important factor that helps to determine the growth achieved during the growing period. The narrowest spacing (5 cm and 20 cm intrarow and inter-row) gave the tallest plant than the other spacing combinations (Table 4). In contrast, wider intrarow spacing (15 cm) gave the shortest plants. This might be due to narrow plant/row spacing or higher plant density which has relatively lower interception of light through crop canopy as compared to wider spacing where there is a better light interception. This shows that the competition among the plants for sunlight interception increased as the number of plants in a given area increased. Hence, the difference in plant height was attributed to the interplant competition for light and nutrients. Moreover, prolonged vegetative growth as a result of increased plant density was attributed to increasing plant height [28]. Further, the increase in plant height at higher plant density is possibly due to an increase in the number of nodes per plant and stem elongation as a result of mutual shading [29,30]. Our results are in agreement with Gezahegn and Tesfaye [31] who found a taller faba bean plant in narrow spacing combinations.

On the other hand, the highest number of branches per plant was found from the widest intrarow and inter-row spacing (15 cm × 40 cm), but was not significantly different from 15 cm × 30 and 15 cm × 20 cm intrarow and inter-row spacing (Table 4). The more efficient use of available resources (nutrients, water, and light) in lower plant density contributed to higher branches as compared to higher plant density. The result is in agreement with Agajie [3] who reported the lowest number of branches (1.47) in 20 cm inter-row and 5 cm intrarow spacing. Similarly, Erdogan [32] reported a decreased number of primary and secondary branches as increased plant density at Vertisol of Turkey. Biabani [33], Naik et al. [34], and Cokkizgin [35] also reported the minimum number of branches at the highest plant density due to competition for light, space, and nutrients between the plants.

3.3. Yield and Yield Components. The main effect of site-year, variety, and spacing had a significant ($P < 0.05$) effect on the number of pods per plant, thousands of seed weight and seed yield per plant. However, the interaction effect of variety and spacing was not significant ($P > 0.05$) (Table 3). Yield components of chickpea were higher in 2017 than in 2016 at Debre Zeit, but they were higher in 2016 than 2017 at Minjar. The differences in yield traits between the years were probably due to the variation of total rainfall and its distribution in the cropping seasons (Figures 1 and 2). Habru variety gave a higher number of pods per plant, thousands seed weight, seed yield per plant than did Arerti variety (Table 4). The differences in yield components might be due to varietal differences in genetic makeup. This result is in agreement with Mekuanint et al. [17], who reported a significant varietal difference of chickpea on yield components.

Average over variety, the widest intrarow and inter-row spacing (15 cm × 40 cm) gave the highest number of pods per plant, thousands-seed weight and seed yield per plant (Table 4). As plant density decreased from the narrowest to the widest spacing, the performance of individual plant is expected to be increased. This was probably due to low plant density that enhanced low competition among plants which enabled more aeration, better light interception, and high photosynthesis by the individual plant. More plant growth such as the number of branches per plant and the development of more pods per plant finally led to higher seed yield per plant. The result was in line with the findings of Mirazaei et al. [36] who reported that the number of pods per plant, number of seeds per pod, and the weight of hundred seeds and seed yield per plant were significantly influenced by plant densities. Farjam et al. [37] also reported an improvement of yield components particularly the number of pods per plant of chickpea with increasing distance between rows or decreasing plant density per unit area. Similarly, Gezahegn et al. [24] reported the highest number of pods per plant and seed yield per plant under the widest intrarow and inter-row spacing at Vertisol. Khan et al. [38] found a significant effect of plant density and planting arrangement on the number of pods per plant and seed per pod, and the highest was obtained under 15/45 cm paired rows. They also suggested that optimal plant density and planting arrangement possibly changed under different environments. Yield traits such as pods and seed yield per plant of individual plants were more affected by intrarow spacing than by inter-row spacing. Worku and Astatkie [39] also found that yield components of soybean were mainly affected by plant spacing as compared to row spacing. In contrast, Ferreira et al. [40] reported that narrower row spacing gave higher production of pods and grains per plant.

Site-year, variety, and spacing had a significant ($P < 0.05$) effect on the seed yield and biomass yield of chickpea. However, the interaction effect of variety and spacing was not significant on those parameters (Table 3). Harvest index was not significantly affected by either the main or interaction effect of variety and spacing (Table 3). Grain and biomass yields in 2017 were higher than in 2016 at Debre Zeit, but the reverse is true at Minjar. The differences in grain yield and biomass yield between years is probably due to the variation of rainfall distribution and amount in the cropping seasons. Habru gave a higher seed yield (2216.3 kg ha^{-1}) and aboveground dry biomass yield (18 383 kg ha^{-1}) than did Arerti (Table 4). The differences in grain yield and biomass yield might have been caused by varietal differences in genetic makeup. Similar to this finding, Shumi et al. [22] found yield difference of chickpea varieties and Habru was listed among high yielder varieties. Goa [27] also reported that Arerti and Habru were an out yielding variety as compared to other varieties.

Grain yield and dry biomass yield of chickpea increased with decreasing inter-row and intrarow spacing or with increasing plant population. The highest grain yield (2926 kg ha^{-1}) and dry biomass yield (18283 kg ha^{-1} at Debre Zeit) were recorded for 10 cm × 30 cm intrarow and inter-row spacing, but was not significantly ($P > 0.05$) different from values recorded for 5 cm × 20 cm, 10 cm × 20 cm, 5 cm × 40 cm, 15 cm × 30 cm, and 10 cm × 40 cm intrarow and inter-row spacing (Table 4). However, the lowest grain yield was recorded with the widest intrarow and inter-row spacing (15 cm × 40 cm). The possible reason for this could be that when inter-row and intrarow spacing decreased, the number of plants per unit area also increased, resulting in higher yield. This indicated that the main determinant of yield is the number of plants per unit area. Similarly, increases in the number of plants per unit area with decreasing inter-row and intrarow spacing resulted in more efficient utilization of environmental inputs and, thus, provided higher yields. The result was in line with the findings of Agajie [3] and Nawange et al. [2], who reported that 30 cm inter-row and 10 cm intrarow spacing gave the highest grain yield. Thangwana and Ogola [41] also reported a higher seed yield of chickpea (2149 kg ha^{-1}) at the high planting density as compared to low (1035 kg ha^{-1}) planting density. Similarly, Ali et al. [42] found the highest grain yields of chickpea at 30 cm inter-row and 15 cm intrarow spacing. Goyal et al. [43] also recommended 33 plants m^{-2} for the highest grain and straw yield of chickpea at black clay soil of India. Furthermore, the narrowest intrarow and inter-row spacing or the highest plant population density have been stated to improve yield as a result of prompt crop growth and the higher light interception and leaf area index [44, 45].

Both grain and dry biomass yield of chickpea was increased as plant density increases till a specific density threshold was reached (33 plants m^{-2}) after which no further yield increments were observed. Agudamu et al. [46] also explained that an increment of crop yield with plant population density extended to a particular plant population threshold, after that any additional increase in population will probably have a negative impact on yield. Similarly, Gezahegn [47] stated that grain yield declined at very high plant densities due to increasing the number of aborted pods and unfertile pods, whereas it is limited by the number of plants owing to low plant densities. Therefore, optimum plant density and appropriate plant configuration per unit area allows crops to utilize resources optimally and produce a better yield.

The relationship between inter-row and intrarow spacing and grain yield of chickpea are presented in Figures 3 and 4, respectively. The grain yields of chickpea were increased as inter-row spacing increased from 20 cm to 30 cm, but decreased further as inter-row spacing increased to 40 cm. Similarly, the grain yields of chickpea were increased as intrarow spacing increased from 5 cm to 10 cm, but decreased further as inter-row spacing increased to 15 cm. This implies that both inter-row and intraspacing have importance for grain yield of chickpea. This finding is in agreement with Gan et al. [48] who reported that, average over intrarow spacing, the seed yield of chickpea was increased with inter-row spacing up to 30 cm after which seed yield decreased. Day [18] also reported that the seed yield of chickpea was increased by 30.81 and 15.53% as inter and intrarow spacing decreased from 40 cm to 20 cm and 15 cm to 10 cm, respectively.

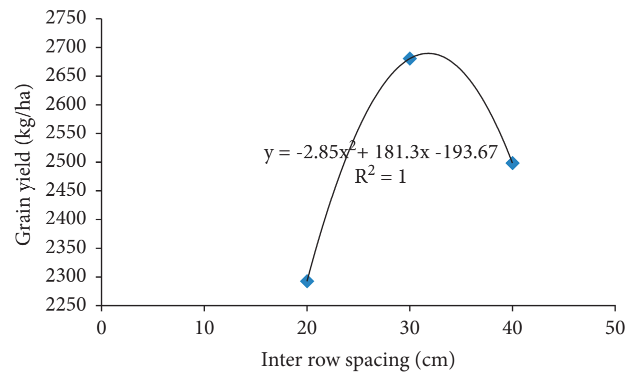

Figure 3: Relationship between inter-row spacing and grain yield of chickpea.

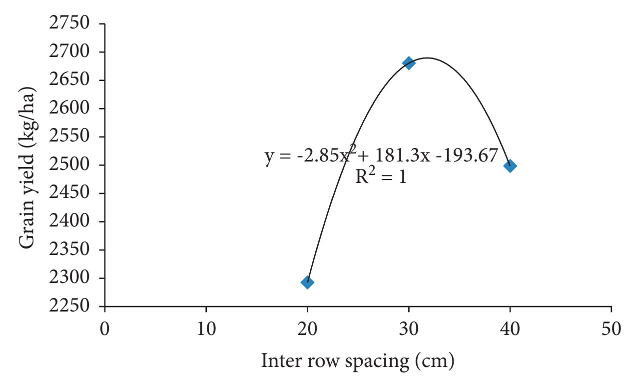

Figure 4: Relationship between intrarow spacing and grain yield of chickpea.

3.4. Economic Analysis. The price of chickpea seeds increases from time to time; therefore, optimizing plant density to maximize yields and economic return is very crucial. The economically optimum plant density can be found when the margin between the values of seed produced and production cost is maximized. The result of the partial and marginal analysis (Table 5) showed that the highest net benefits (ETB 90502 ha^{-1}) were obtained from 10 cm × 30 cm followed by 10 cm × 40 cm of intrarow and inter-row spacing (ETB 82414 ha^{-1}). On the other hand, the highest marginal rate of

Table 5: Economic analysis for inter-row and intrarow spacing of chickpea over site and year.

Treatment	Plants ha^{-1}	GY (kg ha^{-1})	AGY (kg ha^{-1})	GB (ETB)	TCV (ETB)	NB (ETB)	MRR (%)
15 cm × 40 cm	170,000	2144	1930	67536	833	66703	
15 cm × 30 cm	220,000	2573	2316	81050	1111	79939	4761
10 cm × 40 cm	250,000	2656	2390	83664	1250	82414	1781
10 cm × 30 cm	330,000	2926	2633	92169	1667	90502	1940
15 cm × 20 cm	330,000	1970	1773	62055	1667	60388	
10 cm × 20 cm	500,000	2441	2197	76892	2500	74392	1681
5 cm × 40 cm	500,000	2695	2426	84893	2500	82393	
5 cm × 30 cm	670,000	2542	2288	80073	3333	76740	
5 cm × 20 cm	1,000,000	2466	2219	77679	5000	72679	

GY = grain yield, AGY = adjusted grain yield (10% down), GB = gross benefit, TVC = total variable cost, and NB = net benefit.

return (MRR) (4761%) was obtained from the treatment of 15 cm × 30 cm spacing followed by 10 cm × 30 cm (1940%). In contrast, the lowest net benefit was recorded in 15 cm intrarow and 40 cm inter-row spacing. The highest cost (ETB 5000 ha^{-1}) was recorded for 5 cm × 20 cm intrarow and inter-row spacing. An increased plant density increased the costs of products directly through increased seed cost, seed treatments, and crop management [48]. The partial budget, marginal analysis, and minimum rate of return together give the information necessary to arrive at a tentative or candidate recommendation. Therefore, 30 cm inter-row and 10 cm intrarow spacing (33 plants m^{-2}) gave the highest net benefit with a MRR which was higher than the minimum rate of return (100%). Similarly, Gezahegn et al. [24] reported that 30 cm inter-row and 8 cm intrarow spacing (42 plants m^{-2}) gave the highest net benefit and MRR of faba bean.

4. Conclusion

Variety and inter-row and intrarow spacing had a significant effect on the yield and yield components of chickpea at both locations. Intrarow and inter-row spacing of 10 cm × 30 cm gave the highest yield at both locations, but it did not show significant differences from 15 cm × 30 cm, 10 cm × 40, and 5 cm × 40 cm. Results of the economic analysis also revealed that 10 cm × 30 cm intrarow and inter-row spacing gave the highest net benefit as compared to the other treatments. Therefore, 10 cm × 30 cm of intrarow and inter-row spacing (33 plants m^{-2}) can be recommended for higher and economically the optimum yield of chickpea at Debre Ziet and Minjar and in areas with similar agroecology in the country.

Data Availability

The row data are the properties of the institute, so the row data cannot be shared.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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