Journal of Biology, Agriculture and Healthcare
ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)
Vol.6, No.3, 2016

Effect of Inter-And Intra-Row Spacing on Growth and Yield of Okra [*Abelmoschus esculentus* (L.) Moench] at Humera, Northern Ethiopia

Haile Zibelo (MSc)* Professor Kebede W/tsadik (PhD) Professor J.J.Sharma (PhD)
Tigray Agricultural Research Institute, Humera Agricultural Research Center, P.O. Box 62,Humera, Ethiopia

Abstract
Okra [Abelmoschus esculentus (L.) Moench] has a special status in the field of nutrition and health care. In Humera, the major okra production constraints are improper inter-and intra-row spacing, use of local varieties (low yielding), inappropriate planting dates, soil nutrients and insect pests. Field trial was conducted to determine appropriate inter-and intra-row spacing for higher yield of okra under Humera condition, northwestern Ethiopia for three years (2012 to 2014 main cropping seasons). The experimental site is situated at an altitude of 568 m.a.s.l. and the texture of the soil is chromic Vertisol. Factorial combinations of four inter row spacings (30, 45, 60 and 75 cm) and four intra row spacings (15, 20, 25 and 30 cm) were laid out in RCBD replicated three times. Leaf area index at 15 days after emergence, both plant height and number of leaves plant^{-1} at 15 and 30 days after emergence, days to pod setting, green pod length, diameter and weight were significantly ($p<0.05$) affected by the main effects of inter-and intra-row spacing. Similarly, significant interaction effects of inter-and intra-row spacing were recorded for plant height at flowering and last picking, number of leaves plant^{-1} at flowering, leaf area index at 30 days after emergence and flowering, number of branches and pods plant^{-1}, length of pod bearing zone, and green pod yield plant^{-1} and ha^{-1}. The highest green pod yield ha^{-1} (24.51t) was obtained from a spacing combination of 45 cm x 25 cm, being not significant from 45 cm x 30 cm spacing. Therefore, it can be concluded that okra could be planted at inter row spacing of 45 cm and intra row spacing of 25-30 cm in Humera area to maximize green pod yield. Since this study was the first of its kind in the country, research concerning all other pre-and post-harvest crop management practices along the variability study (varietal screening) should be undertaken to improve production and productivity of the crop at a national level. It would also be logical to promote the production of the crop to contribute its part in alleviating the malnutrition and poverty for the ever-increasing population.

INTRODUCTION

Okra [*Abelmoschus esculentus* (L.) Moench], also known as Lady's finger is a common vegetable crop grown under tropical and subtropical conditions. Being native to tropical Africa (extending from Ethiopia to the Sudan), it is prized vegetable in many countries (Chadha, 2002). Okra is especially valued for its tender delicious fruits and is a good source of essential vitamins (e.g., Vitamin C) and minerals such as calcium, phosphorus, magnesium and iron. It possesses high nutritive value, which is higher than tomatoes, eggplant and most cucurbits except bitter gourds (Berry *et al*., 1999). The dried okra pods are consumed directly and they are also used as flavoring in preparing other food products. Okra is also valuable with regards to anti-carcinogenicity, human immunity promotion, ageing prevention and health-care (Lee *et al*., 2001; AVRDC, 2003).

Okra can be eaten grated raw or cooked. The seeds of okra have been used as coffee substitute and edible oil could also be extracted from dried okra seeds. The amino acid profile of the seed indicates that it could be used to complement other partially complete protein sources such as soybean. Apart from its nutritive value, matured fruits and stems containing crude fiber are used in paper industry. Mucilaginous extracts of the green stem are commonly employed for clarifying sugar cane juice (Gopalan *et al*., 2007).

The yield of okra in most of the developing countries is very low (1.77-8 t ha^{-1}) as compared to the yield in developed countries that could reach as high as 30 t ha^{-1} (Whitehead and Singh, 2000). The yield of okra and its quality are hampered severely by inefficient production methods or lack of knowledge about the best cultivation and management practices, low awareness on the nutritional and health benefits, low quality seed standards and limited market accesses. Its production and productivity are also seriously affected due to the use of local varieties (low yielding), sub-or supra-optimal plant density (improper inter-and intra-row spacing), inappropriate planting dates, soil nutrients, and heavy attack of various insect pests and weeds (Saha *et al*., 2005). Even though yield can be improved by selecting high yielding and adaptive varieties (30-40%), the yield elasticity due to variety is low as compared to the natural resource management (60-70%) that includes all inputs and pre-harvest and post-harvest crop management (Whitehead and Singh, 2000). This emphasizes the significance of inter-and intra-row spacing in explaining the yield potential of a given crop.

It has been reported that optimum plant density is the key element for higher yields of okra, as plant growth and yield are affected by inter-and intra-row spacings (Chadha, 2002). One of the major aspects of crop ecology, production and management, which often limit crop production are improper crop spacing systems in the field. Most small-holders of okra farmers produce it at low standard of crop husbandry and rarely care about the spacing. This reduces the number of crops planted ha^{-1} or causes over-crowding; thus, making weeding and other farm operations to be difficult. With increasing plant population, yield per unit area increases until a certain limit, beyond which yield decreases due to limitation of environmental resources required for plant growth. Overcrowding of seedlings or plants in a particular area or spot may lead to competition among the plants for essential growth resources like sunlight, space, water and nutrients; this may thus affect plant performance and yield (Olasantan, 2001).

Several studies on okra plant population density have reported increases in crop productivity as density increased up to 10 plants m^{-2} (Siemonsma, 1998). Whitehead and Singh (2000) also revealed a continuous increase in fruit yield from the lowest (2.4 plants m^{-2}) to the highest density (14 plants m^{-2}). However, Hermann and Singh **(**2003) observed no difference in okra yield at spacing of 4, 8, or 16 plants m^{-2}. They noted that the yield potential, in terms of the number of generative nodes per unit area, was higher in plots with closer spacing (16 plants per square meter). However, due to flower abscission, densely spaced plants failed to realize their yield potential. Similarly, Okunowo (2012) reported no significant difference in yield of okra planted at spacing of 100 cm x 25 cm, 90 cm x 30 cm, 60 cm x 40 cm and 50 cm x 50 cm. On the other hand, Albregts and Howard (2002) observed increases in yield up to 64 plants m^{-2}. Increased yields at higher population densities have also been reported in other vegetable crops such as pepper, tomato and eggplant (Nasto *et al*., 2009).

Okra is originated in Ethiopia and, hence, the agro-climatic conditions are quite favorable both for home garden and commercial farming. However, its production and consumption are neglected and only known and grown in a few parts of the country like Humera (Western Tigray), Gambella, and Benshangul Gumuz. Even in those cultivation areas, people grow conventionally and no attention has so far been given for the development of improved agronomic management practices (EARO, 2002).

Being a minor crop, farmers and even researchers are not aware of its basic agronomy and growing requirements; as a result, the effect of inter-and intra-row spacing on growth and yield of okra has not been investigated in the target area in particular and in the country in general. Keeping in view the potential of the crop and the problem being faced by farmers to grow other crops because of mono-cropping (sesame and sorghum) in Humera area, it is of paramount importance to conduct and develop optimal agronomic management practices such as inter-and intra-row spacing for the crop. From this point of view, therefore, any production strategy for boosting the yield of this crop will be of immense benefit to the society. This will undoubtedly help to narrow down the gap between farmers' yield and potential yield thereby enabling expansion of its production and consumption in the area. Therefore, study was undertaken to determine appropriate inter-and intra-row spacing for higher yield of okra.

MATERIALS AND METHODS

The experiment was conducted for three years (2012 to 2014) at Humera Agricultural Research Center, Kafta Humera wereda, western zone of Tigray regional state, northern Ethiopia during the main growing seasons. It is found in the north escarpment of the country bordered in the west with the Sudan, in the north with Eritrea, in the south with the Amhara regional state and in the east with Welkait-Tsegedie wereda of Tigray regional state. Humera is found about 600 km to west of Mekelle. It is located between 13°14' N and 36°27' E (BoARD, 2004). The dominant soil type of the area is chromic *Vertisol* black in color and characterized with very deep (>150 cm) clay texture (40-60% clay content), electrical conductivity of 0.047-0.179 mmohs/cm, low organic matter content (<2%) and CEC ranges from 37 to 77 meq/100g soil (EARO, 2002). The agro-ecology of the area is hot to warm semi-arid low land plains described as SA1-1with an altitude of 568 meters above sea level. It is characterized by hot temperature, erratic rainfall, vast area of plain low lands suitable for large scale and subsistence agriculture including crops and livestock. The maximum temperature varies from 42°C in April to 33°C in August while minimum temperature varies from 22.2°C in May to 17.5°C in July. The average annual rainfall is 448 mm and the mean annual temperature varies from 25°C-27°C (BoARD, 2004). However, according to the current meteorological data of Humera meteorological station, the mean annual temperature and total rainfall during the study was 24.4°C and 510 mm, respectively.

Local okra cultivar was used in running the experiment. The treatment combinations include inter row spacing of 30, 45, 60 and 75 cm, and intra row spacing of 15, 20, 25, and 30 cm, having a total of 16 treatments. The treatments were arranged in a factorial combination using randomized complete block design with three replications. The gross plot size was 3.6 m x 3.0 m. Experimental blocks and plots were spaced 1.5 m and 1 m apart, respectively. There were 12, 8, 6 and 5 rows in each plot with inter row spacing of 30, 45, 60 and 75 cm, respectively. In intra row spacing of 15, 20, 25 and 30 cm the total number of plants in each row were 20, 15, 12 and 10, respectively. The data was recorded from inner 8, 5, 4 and 3 rows in plots having an inter row spacing of 30, 45, 60 and 75 cm, respectively. From each row, both ends 7 (4+3), 5 (3+2), 4(2+2) and 3(2+1) plants were regarded as border plants under 15, 20, 25 and 30 cm intra row spacing, respectively. The net plot area used to record the observations and yield for each plot was 2.4 m x 2.0 m.

Nitrogen fertilizer (69 kg N ha^{-1}) was applied in two equal splits, each at sowing and flower initiation, while the whole amount of phosphorus (46 kg P_2O_5) was applied at sowing. The sources of the fertilizers were di-ammonium phosphate (DAP; 18% N + 46% P_2O_5) and urea (46% N). At sowing, 100 kg DAP ha^{-1} was applied that provided 18 kg N and 46 kg P_2O_5 ha^{-1} and 36 kg urea ha^{-1} was supplied (16.5 kg N ha^{-1}) to meet the initial crop requirement while the remaining urea (75 kg ha^{-1}) was top dressed at flower initiation to meet the whole blanket crop requirement as per the recommendation of Akande *et al*. (2003). All other crop management practices prevalent in the area were followed uniformly for all plots.

Fifteen days after the crop emergence, ten plants in the net plot area of each plot were randomly tagged to record all the observations except crop stand and yield. The following parameters were recorded at their appropriate time from the net plot area during the crop growth period:

Plant height (cm): Plant height was measured at 15 and 30 days after emergence (DAE), at flowering, and at last picking with meter from ground level to the tip of main shoot.

Number of leaves per plant: This was determined by carefully counting the number of leaves of sample plants at 15 and 30 DAE, and at flowering stage.

Leaf area per plant: The leaf area measurement was taken by measuring the length of median lobe of individual leaf on the plant at 15 and 30 DAE and at flowering; applying the following formula used by Olasantan and Asif (1999): $Y = 115X – 1050$; Where: Y = Leaf area (cm^2), X = length of median lobe (cm). The area of all leaves on a plant was added up to give leaf area per plant.

Leaf area index: The leaf area index was calculated by dividing the leaf area per plant by the land area occupied by the plant at 15 and 30 DAE, and at flowering.

Days to flowering: The number of days taken from crop emergence to 50% of the plants start flowering in each plot was recorded.

Days to pod setting: The total number of days taken from emergence to the stage at which 50% of the plants in each experimental plot set at least one pod per plant was recorded.

Length of pod bearing zone (cm): The length of stem from the point of pod beginning to the point where pod formation ends was measured.

Number of branches per plant: The number of primary branches per plant was recorded from the sample plants at last picking.

Number of green pods per plant: The average number of green pods per plant was computed by summing up all pods harvested from sample plants.

Green pod length: The length of the green pods recorded from sample plants was measured and average length was computed in cm.

Green pod diameter: This was measured from three (bottom, center and top) portions of the pods from the sample plants and their average was taken.

Green pod weight: Average weight (g) of a single pod was determined by taking weight of pods from all harvests from the sample plants.

Green pod yield per plant (kg): Yield of green pod per plant was determined by summing and averaging the weight of green pods harvested from the sample plants at all picking times.

Green pod yield per hectare: Yield obtained at each harvest from the net plot area was summed up and converted in to a hectare of land and expressed as total yield (t ha^{-1}).

Crop stand: The number of plants in the net area of each treatment was counted fifteen days after crop emergence and at the time of last harvest.

The data collected were analyzed statistically by constructing ANOVA tables using the SAS analytical software computer package (SAS, 2007). Differences among the treatment means were compared by using Tukey's Studentized Range (HSD) test at 5% level of probability. A correlation matrix was also carried out to assess the strength and direction of a linear association among all the parameters measured.

RESULTS AND DISCUSSION

Days to flowering

The results revealed that effect of the interaction between inter-and intra-row spacing remained non-significant on the number of days required to flower. However, the parameter was significantly ($p<0.05$) affected by inter row spacing and intra row spacing (Table 1). Plants spaced at 30 cm inter row spacing and 15 cm intra row spacing took minimum days to flower (41.99 days and 41.75 days, respectively) while maximum days were recorded with plants spaced at inter row spacing of 75 cm and intra row spacing of 30 cm apart (44.52 days and 44.58 days, respectively). Only inter row spacing of 30 cm and 60 cm, 30 cm and 75 cm and intra row spacing of 15 cm and 25 cm, 15 cm and 30 cm were statistically significant while all the rest were statistically at par (Table 1). Minimum number of days was required to flower where the closest inter row spacing and intra row spacing was adopted, probably in order to escape from the stress and for seed dispersal, resulting in early flowering. Days to 50% flowering, first flowering node, and first fruiting node are the indicators of earliness in okra (Ali, 1999). Early flowering not only gives early pickings and better returns but also widens fruiting period of the plant; flowering and fruiting at lower nodes are helpful in increasing the number of fruits per plant as well as getting early yields. Ali (1999) also reported that inter row spacing and intra row spacing had significant effect on number of days to flower in okra. According to the author, plants with closest row to row and plant to plant spacing flowered earlier and vice versa. Moreover, Salehi and Bahrani (2000) reported significantly delayed flowering of sunflower planted at wider spacing than the denser ones. Turk *et al.* (2003), working on lentil, noted that the denser plant population hastened the days to flowering. Therefore, the results of the present study are in accordance with such previous findings. On the contrary, Singh (1996) and Abdul (1999) reported that plant spacing had non-significant effect on number of days to flower in okra. Likewise, increased plant density in faba bean did not affect the days to flowering but hastened uniformity in maturity (Amato *et al*., 1992).

Table 1. Main effect of inter-and intra-row spacing on days to 50% flowering and days to 50% pod setting of okra at Humera, northern Ethiopia

Treatments	Days to 50% Flowering	Days to 50% pod setting
Inter-row spacing (cm)		
30	44.08	49.24^{b}
45	45.58	51.33^{ab}
60	45.00	52.58^{a}
75	45.58	53.17^{a}
Intra-row spacing (cm)		
15	43.00^{b}	48.17^{c}
20	44.42^{ab}	50.33^{b}
25	45.67^{ab}	51.58^{a}
30	47.17^{a}	52.17^{a}
CV (%)	5.72	4.37

Means within a column for a parameter sharing common letter(s) are not significantly different at 5% probability level according to Tukey's Studentized Range (HSD) test; CV= coefficient of variation

Days to pod setting

Statistical analysis of the data for days to 50% pod setting showed significant differences among the different spacing treatments (both inter-and intra-row); but, the interaction was non-significant. Statistically maximum days to 50% pod setting (49.80 days) was recorded in inter row spacing of 75 cm while minimum number of days to 50% pod setting (47.79 days) was observed in inter row spacing of 30 cm (Table 1). Similarly, intra row spacing of 30 cm significantly delayed days to 50% pod setting of okra plants while the narrowest intra row spacing (15 cm) enhanced days to pod setting by about 3 days compared to the widest spacing. It can be seen from Table 1 that the plants spaced 15 cm apart showed significant difference from all other intra row spacing treatments with the exception of 20 cm.

In general, plants in the closer spacing (both inter-and intra-row) took minimum days to 50% pod setting and plants in the wider spacing were late to bear pods. This could be due to the fact that plants in the wider spacing took more days to flower; as a result, they should have taken more days to bear pods too. Vegetables marketed early in the season usually bring premium prices; thus closely spaced okra plants not only produce higher yields but could also provide the added economic advantage of early harvests. This is in conformity with the report by Ekwu and Nwokwu (2012) who observed days to 50% pod setting of okra decreased as the plant spacing increased from 50 cm x 25 cm to 50 cm x 75 cm. Additionally, increased plant density in faba bean did not affect the days to flowering but hastened uniformity in maturity (Amato *et al*., 1992). In contrast to the present finding, Oad *et al.* (2002) reported wider inter-and intra-row spacing along with their interaction effect, hastened maturity of safflower. Wider inter row spacing was also found to hasten physiological maturity of sesame crop while the main effect of intra row spacing and the interaction of any of the factors did not affect significantly (Gebre, 2006). Furthermore, days to 50% maturity of *Vernonia galamensis* was affected neither by the main effects of inter-and intra-row spacing nor by their interaction (Abebe, 2007). These inconsistent results indicate the importance of crop and location specific nature of plant population experiments.

Plant height

The effect of inter row spacing on plant height both at 15 and 30 DAE and intra row spacing at 15 and 30 DAE were found to be significant ($P< 0.05$) while the interaction effects of inter-and intra-row spacing at both growth stages were non-significant.

Regarding the inter row spacing at 15 DAE, plants spaced 30 cm apart were found to be about 11% taller than the average of plants grown on 60 cm and 75 cm inter row spacing, which had values that were at par.

Similarly, 30 DAE, the narrowest inter row spacing (30 cm) resulted in plants that were about 16% taller than those from 30 cm spacing (Table 2). Likewise, the narrowest intra row spacing (15 cm) at 15 DAE and 30 DAE resulted in plants that were significantly taller (11.4%) than the rest inter row spacing treatments (27% and 21%, respectively). The result agreed with the reports of Manuel *et al*. (1998) and Moniruzzaman *et al.* (2007) that showed increased plant height and reduced branches with increase in plant density of okra. Pedersen (2008) also reported that plant height increased with increasing plant density and node number on stem reduced in soybean. Thus, increasing height in high densities is due to increasing node spacing, affected by reducing sunlight penetrating into canopy.

Plant height at flowering and final harvest period was significantly ($p<0.05$) affected by both inter row spacing and intra row spacing and by the interaction effects of inter-and intra-row spacing. The maximum plant height at flowering (85.74 cm) was recorded when plants were spaced at 30 cm x 15 cm; however, this value did not vary statistically from spacing of 30 cm x 20 cm and 30 cm x 25 cm spacing combinations. On the other hand, the lowest plant height (64.16 cm) was obtained from the wider spacing (75 cm x 30 cm), which was also at par with plants from inter row spacing of 75 cm and 60 cm combined with intra row spacing of 15 cm, 20 cm and 25 cm as well as combinations of 45 cm x 25 cm spacing. Similar trends in plant height were also observed at the final harvest stage (Table 3).

In general, plant height showed an increase with decrease of both inter-and intra-row spacing. The observed increase in plant height as population density increased could be due to intense competition between and within plants and their desire to reach for the essentials of life, light energy in this case. These results could be due to less space available in the narrowest spacing, which discourages growth of lateral branches and favors plants to grow upward in competition for light. When plants are spaced too closely, they grow tall to reach for the light, developing long, scrawny branches that tend to be weak; ultimately, plants do not produce as many leaves, flowers, fruits or seeds as compared to plants that have optimum light (Pedersen, 2008). Overall, too narrow spacing causes light to limit branching growth and threatens plant health due to exposure to more humid conditions; compromising the amount to be harvested (Caliskan *et al.,* 2004). It is obvious that under such conditions, plant height was increased while number of branches was reduced.

The result of the present study was in conformity with that of Gupta and Shukla (2000) who reported a taller okra plant when grown at a closer intra row spacing of 30 cm than at a wider intra row spacing of 40 cm. This result was also in agreement to the findings of Absar and Siddique (2001) who reported increase in plant height with increasing plant density from 2-8 weeks after planting in okra crop. Similar results were observed by Lee *et al*. (2001) who noted that the plant height in three cultivars of okra was increased with increasing plant density with advance in their growth stages; though non-significant effect was found by Odeleye *et al*. (2005) at spacing treatments ranging from 60 cm x 40 cm to 60 cm x 20 cm. In addition, Ekwu and Nwokwu (2012) reported that okra plant height increased as the plant spacing increased from 50 cm x 25 cm to 50 cm x 50 cm beyond which there was a decrease in plant height. The result also agreed with the reports of Manuel *et al*. (1998) and Moniruzzaman *et al.* (2007) that showed increased plant height and reduced branches with increase in plant density of okra. Mehla *et al*. (2000) found increased plant height in tomato at closer spacing than at wider spacing; closer spacing of 60 cm x 45 cm and 80 cm x 30 cm resulted in significantly higher plant height compared to a wider spacing of 100 cm x 30 cm, which was also in line with the present result. The same trend was also reported by Tesfaye (2005) in tomato and Olasantan (2001) in cassava crop; plant height at flowering increased in closer spacing than at wider spacing.

Conversely, Cushman *et al*. (2005) stated that densely spaced okra plants were the tallest early in the trial due to elongation of inter-nodes, but widely spaced plants were tallest by the end of the trial since differences in number of inter-nodes then out-weighed the influence of inter-node length on plant height. In addition, higher plant height was observed in wider inter-and intra-row spacing while the lowest plant height was from the narrow row and plant spacing in sesame (Gebre, 2006). Turk *et al.* (2003) and Caliskan *et al.* (2004) also reported similar findings on lentil and sesame, respectively; that plant height was correlated negatively with plant density. This might have attributed to a greater assimilation of growth resources for the plants grown at the wider spacing and the indeterminate growth habit of the crop might encourage vegetative growth.

Table 2. Main effect of inter-and intra-row spacing on growth of okra at Humera, northern Ethiopia

Treatments	Plant height (cm) at		Number of leaves plant^{-1} at		Leaf area index at
	15 DAE	30 DAE	15 DAE	30 DAE	15 DAE
Inter-row (cm)					
30	12.64	40.51^{a}	5.55	17.81^{b}	0.13^{a}
45	12.41	38.86^{a}	5.89	21.43^{a}	0.10^{b}
60	12.20	36.51^{ab}	5.84	19.92^{ab}	0.07^{c}
75	11.48	33.74^{b}	5.84	18.83^{ab}	0.06^{d}
Intra-row (cm)					
15	14.20^{a}	41.66^{a}	5.29^{b}	17.15^{b}	0.12^{a}
20	11.85^{b}	37.43^{ab}	5.95^{a}	20.49^{a}	0.09^{b}
25	11.52^{b}	35.69^{b}	5.97^{a}	20.62^{a}	0.08^{bc}
30	11.16^{b}	34.84^{b}	5.91^{a}	19.72^{ab}	0.07^{c}
CV (%)	16.89	11.36	6.94	12.73	14.95

Means within a column for a parameter sharing common letter(s) are not significantly different at 5% probability level according to Tukey's Studentized Range (HSD) test; DAE= Days after emergence; CV= coefficient of variation

Number of leaves per plant

As can be seen from Table 2, the mean number of leaves per plant both at 15 DAE and 30 DAE was significantly affected by inter row spacing and intra row spacing treatments. At both stages, only inter row spacing of 30 cm has shown significantly ($p < 0.05$) lower number of leaves compared to the rest two inter row spacing (45 cm, 75 cm). The same trend was observed in the intra row spacing treatments. But, the interaction was not statistically significant on number of leaves per plant both at15 DAE and 30 DAE. This can be attributed to the less competition for available nutrients, water and light by the plants in the early growth and development stages (Mehla *et al*., 2000).

Inter row spacing of 45 cm and intra row spacing of 25 cm gave the highest number of leaves per plant at all growth stages of the crop. The highest number of leaves per plant at 15 DAE, 30 DAE and at flowering (4.85, 13.56 and 31.26 leaves, respectively) was achieved with inter row spacing of 45 cm, being statistically not significant with inter row spacing of 75 cm at 15 DAE and with all row spacing at 30 DAE, but significant to all row spacing at flowering stage with the exception of 45 cm x 20 cm, 45 cm x 30 cm, 60 cm x 20 cm. The highest significant number of leaves per plant in intra row spacing at these growth stages was related to the corresponding 25 cm (5.33, 13.56 and 31.26 leaves, respectively), which was statistically non-significant with 20 cm at flowering stage. On the contrary, the lowest number of leaves per plant of the aforementioned growth stages was obtained at inter row spacing of 30 cm (5.55, 17.81 and 22.96 leaves, respectively) and at intra row spacing of 15 cm (5.29, 17.15 and 23.10, respectively).

Table 3 illustrates the interaction effect of inter-and intra-row spacing on the number of leaves per plant at flowering stage. It was observed that the highest number of leaves per plant (31.26 leaves) was achieved with spacing of 45 cm x 25 cm, being statistically similar with plants grown at inter-and intra-row spacing combinations of 45 cm x 20 cm and 30 cm and 60 cm x 20 cm. On the other hand, the lowest number of leaves per plant (17.95 leaves) was found in plants from the treatment combination of 30 cm x 15 cm. This result explains that the adoption of wider inter-and intra-row spacing combinations stimulated plant growth and development by increasing the number of leaves per plant compared to the lowest pairs of spacing.

There was an increase in the number of leaves with increase both in row and plant spacing up to 45 cm x 25 cm spacing combination; soon after, a trend of decline was followed. This trend occurred as plants in the wider spacing experienced large-sized leaves rather than merely increases in leaf number. Therefore, this result elaborates the effect of row and plant spacing as a result of different plant population density per unit area that caused higher and lower number of leaves per plant. Cushman *et al*. (2005) grew 'Clemson Spineless' okra in a greenhouse and observed that number of leaves and generative nods increased with wider spacing combinations initially, but reduced at further reduction of plant population density. This was also in line with the finding of Iremiren and Okiy (1999) who reported significant differences in the number of okra leaves among different spacing treatments; the highest number of leaves per plant obtained at the intermediate and wider spacing. Report from Gebre (2006) magnifies wider inter-and intra-row spacing significantly increased the number of leaves during the course of observation in sesame crop; probably this could be most likely due to the availability of growth factors and better penetration of light at the wider spaced plants.

Number of leaves per plant is an important parameter considering the highest performance of okra yield (Gupta and Shukla, 2000). These authors reported that the number of leaves produced by a plant is directly proportional to the photosynthate produced. This is because leaves are the site of photosynthetic activities of crops through which biomass are produced, partitioned among various parts of crops and stored for crop productivity. Manuel *et al*. (1998) indicated that when photosynthesis becomes active in a young seedling, the power of the plant to synthesize new materials is clearly dependent on the amount of leaves exposed to direct sunlight. The higher the number of leaves, the higher the rates of photosynthesis with resultant increase in carbohydrate production and hence increase in food production. But, on the other hand, fewer leaves means a lower LAI, resulting in less light interception and, hence, a lower total biomass production. Therefore, light interception can be altered by changing row and plant spacing and plant/row orientation to attain the potential yield of a crop.

Table 3. Interaction effect of inter-and intra-row spacing on plant height, number of leaves and leaf area index of okra at Humera, northern Ethiopia

Spacing (cm)		Plant height (cm) at		Number of leaves plant^{-1} at flowering	Leaf area index at	
Inter-row	Intra-row	Flowering	Final harvest		30 DAE	Flowering
30	15	93.57^{a}	110.27^{a}	19.44^{f}	0.85^{a}	3.05^{a}
30	20	93.23^{a}	110.53^{a}	21.54^{f}	0.66^{b}	2.36^{b}
30	25	91.23^{ab}	108.23^{ab}	22.34^{ef}	0.58^{c}	1.93^{c}
30	30	80.67^{bcde}	97.67^{cd}	22.55^{ef}	0.50^{d}	1.64^{de}
45	15	85.50^{abc}	101.83^{bc}	21.94^{ef}	0.59^{c}	2.05^{c}
45	20	84.07^{abcd}	101.73^{c}	33.04^{a}	0.51^{d}	1.76^{d}
45	25	79.40^{cde}	96.40^{cde}	34.51^{a}	0.40^{ef}	1.43^{f}
45	30	76.17^{cde}	93.17^{defg}	30.74^{ab}	0.36^{gh}	1.18^{hi}
60	15	78.80^{cde}	95.60^{cde}	22.17^{ef}	0.47^{d}	1.59^{e}
60	20	76.10^{cde}	92.90^{defg}	29.88^{abc}	0.39^{fg}	1.29^{gh}
60	25	74.37^{cde}	91.07^{efg}	27.74^{bcd}	0.33^{h}	1.08^{ij}
60	30	70.90^{e}	88.87^{fg}	25.91^{cde}	0.29^{i}	0.91^{kl}
75	15	78.00^{de}	95.00^{def}	23.51^{def}	0.43^{e}	1.33^{fg}
75	20	73.87^{de}	90.97^{efg}	27.71^{bcd}	0.34^{h}	1.01^{jk}
75	25	72.13^{e}	88.97^{fg}	25.99^{cde}	0.27^{i}	0.85^{lm}
75	30	71.53^{e}	88.43^{g}	25.51^{cde}	0.23^{j}	0.73^{m}
CV (%)		4.64	2.74	6.01	2.66	2.77

Means within a column for a parameter sharing common letter(s) are not significantly different at 5% probability level according to Tukey's Studentized Range (HSD) test; CV= coefficient of variation

Leaf area index

The data revealed that inter-and intra-row spacing influenced significantly the LAI at 15 DAE while their interaction remained not significant. Only inter row spacing of 30 cm significantly differed from the rest inter row spacing treatments; having the highest LAI of 0.13 from the closest inter row spacing of 30 cm while the corresponding lowest LAI of 0.10 was found from the highest inter row spacing of 75 cm (Table 2). Intra row spacing of 30 cm produced the minimum LAI of 0.10 while the greatest value of LAI (0.13) was obtained from intra row spacing of 15 cm; being significantly different from other intra row spacing treatments. There was also no significant variation between the intra row spacing of 20 cm, 25 cm and 30 cm in LAI of okra at the stage of 15 DAE.

On the other hand, the effect of plant population density (inter-and intra-row spacing and their interaction) on leaf area index both at 30 DAE and at flowering was statistically significant (Table 3). Both at 30 DAE and at flowering, the highest values of leaf area index (0.75 and 2.83, respectively) were obtained from the closest spacing combination of 30 cm x 15 cm whereas the lowest LAI (0.20 and 0.77 at respective stages) were found from the widest spacing combination of 75 cm x 30 cm. The result showed that LAI increased as plant population density increased and this trend was similar at all growth stages of the plant (15 and 30 DAE and at flowering). The wider the spacing, the lesser was the plant producing LAI while the reverse also holds true at all growth stages of the crop. In short, at all growth stages, greater LAI was recorded at closer row and plant spacing treatments than at wider ones.

Although the narrower spacing produced smaller plants with lower leaf area, on a per unit area basis, a factor in determining LAI, more plants in narrow spacing resulted in higher LAI. This indicates that higher number of plants per unit area in the narrow spacing compensated for the lower leaf area per plant; resulting in higher LAI. A plant's ability to compensate for variations in density has been demonstrated in several crops. In the earlier stages of growth, plants at higher densities develop greater LAI, but by the time full canopy forms, such differences largely disappear (Manuel *et al*., 1998). This occurs because plants at lower densities branch more and produce leaves on these branches, thus increasing canopy size. Manuel *et al*. (1998) found highest LAI of 1.94 from the highest planting density of okra crop while the lower LAI of 1.31 and 1.36 were obtained from wider spacing treatments (0.50 m x 0.31 m and 0.50 m x 0.41 m, respectively). Cushman *et al*. (2005) observed a decrease in leaf area, but an increase in LAI as plant population density increased in okra.

LAI is a measure of leafiness per unit ground area and denotes the extent of photosynthetic machinery i.e. LAI of the crop at a particular stage of growth indicates the size of assimilatory system that ultimately contributes towards dry matter accumulation (Hermann and Singh, 2003). In too thick plant population, canopy photosynthesis is negatively affected due to less light penetration in the crop canopy and more competition for available nutrients which adversely affect plant growth and development; resulting in low yield. On the other hand, in too thin plant population, there is less light interception due to lower LAI and more weeds germinate and grow rapidly which also result in lower yield (Mohammad *et al*., 2012). Therefore, light interception can be altered by changing row and plant spacing and plant/row orientation to attain the potential yield of a crop. Row and plant spacing have substantial effects on light interception, crop growth rate, total dry matter, and yield component formation (Odeleye *et al*., 2005). Reducing row spacing from 100 cm to 50 cm has been demonstrated to increase light interception and accelerate crop growth rate during the vegetative, flowering/pod formation, and seed filling periods in soybean (Pedersen, 2008). The author noted that during most of the vegetative and flowering/pod formation periods, accelerated crop growth rate was due to increased LAI than to net assimilation rate.

Plant biomass production per unit area of land is directly related to radiation interception (Mohammad *et al*., 2012). The author reported higher radiation interception because of higher LAI at higher plant densities resulted in higher biomass and fruit yield in pepper. This probably explains why okra yield increased as plant density increased up to 45 cm x 25 cm in this study. Furthermore, solar radiation interception by plants levels off at high LAI. Increases in LAI above a threshold (around 3.5–4 for most crops) do not increase radiation interception (Warner, 2003). This explains why increases in plant density of okra above a threshold did not result in increases in yield per unit area of land in the current study. Warner (2003) also stated that penetration of radiation through the canopy decreased as plant density increased in tomato. Likewise, Albregts and Howard (2002) reported that a high LAI at high plant populations (3.2 plants m^{-2}) resulted in improved light interception and, consequently, in higher biomass and yield of green pepper than at low plant populations (2 plants m^{-2}).

Number of branches per plant

There was a significant ($p<0.05$) difference in the number of branches per plant as affected by inter-and intra-row spacing and their interactions. The number of branches per plant decreased as the spacing combinations reduced (Table 4). Maximum number of branches per plant (2.16) was obtained from the widest plant spacing combination (70 cm x 30 cm). On the other hand, the lowest numbers of branches per plant (0.28 to 0.32) were recorded from the narrow spacing combinations of 30 cm x 15 cm, 30 cm x 20 cm and 45 cm x 15 cm combinations with values that were statistically at par.

The production of more branches at the wider spacing might be attributed to the more efficient use of available growth nutrients, water and light energy, that could favor more photosynthesis and allocation of carbohydrate for all growth points as compared to the closest spacing. On the other hand, plants spaced closer gave less number of branches per plant; the decrease in branch number was parallel with the increase in both row to row and plant to plant spacing. The observed gradual decline in number of branches per plant as population density increased was in line with earlier report of Allen and Wurr (2003) on potato plant. The result observed in the current investigation also supports earlier findings where greater numbers of branches were recorded due to wider spacing and lesser plant density in okra (Lyon *et al*., 2010). Our result was also in line to the findings of Saha *et al*. (2005) who reported a greater branch number at wider inter-and intra-row spacing of 40 cm x 30 cm compared to that produced from reduced spacing of 40 cm x 20 cm. Furthermore, closer row and plant spacing of safflower has been reported to produce more branches per plant than those of the wider ones (Salehi and Bahrani, 2000).

Close spacing increases competition among adjacent plants for available soil nutrients and water, as well as for aerial space for canopy formation. This prevents profuse branching and production of nodes on those branches for flowering and pod set. Singh (1996) showed that fruit retention was 23% greater in okra when plant density was 4 rather than 16 plants m^{-2}. Again, Manuel *et al*. (1998) pointed out as row and plant spacing of okra increased the number of branches per plant increased. In addition, the increase in branch number of okra was linear with the increase in within row spacing (Whitehead and Singh, 2000). The result also agreed with the reports of Moniruzzaman *et al*. (2007) that showed increased plant height and reduced branches with increase in plant density of okra. This could be explained in such a way that, as plant spacing increased in both directions, ample resources become available for each plant that enhances the lateral vegetative growth of the crop. This also indicated the plasticity response of plants to various plant spacing, *i.e*. increased in plant population is associated with a progressive decline in number of branches up to a certain limit beyond which plants become mono-culms whereas, plants at lower density produce higher number of branches in order to compensate the dry matter per unit area of higher densities. According to Albregts and Howard (2002), secondary branches in okra contribute less to yield than does the same as the main stem. This could explain, in part, the yield advantage of higher plant densities in okra. Additionally, Caliskan *et al*. (2004) found taller and more branched plants at the lower plant densities of sesame. Oad *et al.* (2002) also noted that safflower crop kept in the wider plant spacing of 30 cm produced more branches than 22 cm plant to plant spacing.

Number of green pods per plant

The number of green pods per plant varied among the different inter-and intra-row spacing and their interaction. Results pertaining to the number of green pods per plant depicted that maximum number of green pods per plant was recorded in plants spaced at 75 cm × 30 cm (25.75) which was statistically at par with those planted at the spacing combinations of 75 cm × 25 cm and 20 cm, 60 cm × 30 cm, 25 cm and 20 cm, 45 cm × 30 cm, 25 cm and 20 cm, and 30 cm x 30 and 25 cm. The minimum number of green pods per plant (14.31) was recorded from 30 cm × 15 cm which was statistically at par with those planted at 30 cm x 20 cm, 45 x 15 cm, 60 cm x 15 cm and 75 cm x 15 cm spacing combinations (Table 4).

The number of pods per plant is an important factor to increase the yield of okra (Singh, 1996). Number of pods per plant depends upon the number of branches per plant, as more branches were observed in wider spacing which ultimately gives higher number of pods per plant. This was probably because plants had competition for nutrients, water and light in closer spacing, thus resulting in less number of green pods per plant. But, sparsely spaced plants have ample access to nutrients, moisture and light and thus profuse lateral growth takes place; as a result, number of branches and pods per plant increases. Higher branching observed in wide row and plant spacing was a major cause of the increased number of pods per plant. Singh (1996) showed that fruit retention was 23% greater in okra when plant density was 4 rather than 16 plants m^{-2}.

Table 4. Interaction effects of inter-and intra-row spacing on number of branches, pod bearing zone and pod number of okra at Humera, northern Ethiopia

Spacing (cm)		Number of branches plant^{-1}	Length of pod bearing zone (cm)	Number of pods plant^{-1}
Inter-row	Intra-row			
30	15	0.30^{d}	31.87^{g}	17.08^{d}
30	20	0.32^{d}	33.47^{fg}	18.75^{d}
30	25	0.87^{c}	40.30^{def}	20.05^{cd}
30	30	1.02^{bc}	44.57^{bcde}	20.59^{bcd}
45	15	0.34^{d}	37.83^{efg}	19.55^{cd}
45	20	2.05^{a}	51.90^{a}	23.05^{abc}
45	25	2.06^{a}	52.43^{a}	24.17^{ab}
45	30	2.06^{a}	50.30^{ab}	24.57^{a}
60	15	1.12^{b}	41.37^{de}	20.08^{cd}
60	20	2.08^{a}	50.53^{ab}	24.65^{a}
60	25	2.09^{a}	49.00^{abc}	24.75^{a}
60	30	2.09^{a}	48.60^{abc}	26.00^{a}
75	15	1.15^{b}	42.87^{cde}	20.68^{bcd}
75	20	2.10^{a}	49.43^{abc}	25.35^{a}
75	25	2.10^{a}	48.77^{abc}	26.38^{a}
75	30	2.13^{a}	46.03^{abcd}	26.71^{a}
CV (%)		4.79	3.58	5.59

Means within a column for a parameter sharing common letter(s) are not significantly different at 5% probability level according to Tukey's Studentized Range (HSD) test; CV= coefficient of variation

Since okra bears a single flower/node, the number of nodes on a plant largely determines the number of pods it can bear. Narrow spacing increases competition among adjoining plants for available soil nutrients and water as well as for aerial space for canopy formation. This prevents profuse branching and production of nodes on those branches for flowering and pod set. Therefore, it would be logical to expect fewer number of fruiting points produced per plant under higher densities, because of fewer blooms per plant under high population. This may lead to the percentage of barren/unfruitful plants increased with increasing the plant density indicating reduction in fruiting points per plant. The number of pods, therefore, would depend on the intensity of growth of the plants. The results are also in line with the findings of Lee *et al*. (2001) who stated that the number of effective branches and pods per plant decreased with increase in plant density of okra. Further study also indicate that the lowest plant density (37000 plants ha^{-1}) resulted in the maximum number of pods per plant and the highest plant density (111000 plants ha^{-1}) in the minimum number in okra (Muhammad *et al*., 2001). The reduced competition for light and reduced over-lapping from adjacent okra plants could have enabled the plants grown at wider spacing to utilize its energy for maximum branching and subsequently, the production of a larger leaf area, greater number of pods per plant and larger pod size (pod weight and diameter). Greater fruit weight and fruit number per plant at wider spacing have also been reported in other vegetable crops such as pepper, tomato and eggplant (Iremiren and Okiy, 1999). Cavero (2001) investigated the influence of plant population on the productivity of green pepper (*Capsicum annuum* L.) using different plant populations (50 000, 62 500, 83 333, 100 000, 111 111, 160 000 and 200 000 plants ha^{-1}) and reported that fruit number and yield per plant decreased when plant population increased from 50 000 to 200 000 plants ha^{-1}. Furthermore, maximum number of pods per plant at wider spacing combinations was reported by Gebre (2006) and Ahmad *et al.* (2002) in sesame crop.

Length of pod bearing zone

ANOVA shows plant population differences from both changes in inter-and intra-row spacing and their interaction effect had significant ($P < 0.05$) influence on the length of pod bearing zone of okra. Maximum length of pod bearing zone (51.61 cm) was recorded in plants spaced at 45 cm x 30 cm, being statistically similar with those at 45 cm x 20 cm and 25 cm, 60 cm x 20 cm, 25 cm and 30 cm, and 75 cm x 20 cm, 25 cm and 30 cm spacing combinations (Table 4). Plants subjected to 30 cm x 15 cm had the minimum length of pod bearing zone (30.46 cm), being not significant with those at 30 cm x 20 cm and 45 cm x 15 cm spacing combinations, irrespective of their final plant height. Thus, it is logical to expect that the longer the height to bear pods, the higher will be the number of pods per plant; resulting better yield of a crop.

Plants compete for limited resources being essential for their life, i.e. light, water, and nutrients. Yet, whole plant growth and competitive ability depends not only on the photosynthetic rate of individual leaves, but also on the geometry and dynamics of a plant's canopy, and the pattern of energy allocation among all organs (Bange and Caton, 2006). Okra produces fruit/pod beginning with the third to sixth node. Pods are continually produced on new nodes of developing stems, which results in several weeks of harvesting. As vegetative growth and fruiting proceed simultaneously for an extended period, the plant is required to maintain a delicate balance in the partitioning of assimilate between vegetative and reproductive parts (Malik and Mondal, 1996). This shows the importance of higher plant height with maximum length of pod bearing zone for better and continuous yield of okra. The increased length of pod bearing portion of okra with increase in planting density up to a certain limit might be a response usually described as morphological plasticity. Lyon *et al*. (2010) had described morphological plasticity as the plant's capacity to change its form in response to varying environmental conditions. Egbe (2005) had recorded similar findings in his work on evaluating agronomic potentials of 15 pigeon pea genotypes in Southern Guinea Savanna of Nigeria. The decreased yields of pigeon pea with increase in plant density might be explained by the same phenomenon. Olowe and Busari (2003) and Gebre (2006) found out length of pod bearing zone increased with increase in inter-and intra-row spacing in sesame; probably due to the reduced inter plant competition at the intermediate inter row spacing, which encourages both lateral and vertical vegetative growth of the plant. On the opposite way, shorter pod bearing zone lengths at the narrow inter-and intra-row spacing and their pair of combinations could be resulted due to the effect of neighboring plants, where competition for growth factors was intense; resulting in a few number of pods per plant.

Green pod length

The different inter-and intra-row spacing adopted differed significantly for length of green pods of okra while their interaction had non-significant effect. Inter row spacing of 75 cm significantly increased pod length compared to narrower spacing at 30 cm. Inter row spacing at 30 cm gave the least mean pod length which was about 22% lower than those at 75 cm inter row spacing. Similarly, intra row spacing of 15 cm resulted in plants with the lowest mean pod length compared to the corresponding wider intra row spacing. While intra row spacing of 30 cm gave pods with maximum pod length, differences with those from 25 cm and 20 cm and 15 cm spacing were not statistically significant. In both cases (inter-and intra-row), the largest and smallest pod length were obtained at the widest and closest spacing, respectively (Table 5).

In general, there was an increase in pod length with the increase in inter-and intra-row spacing. The result of this study was in accordance with that of Gupta and Shukla (2000) who reported that maximum pod length with widest spacing in okra. This result is also in line with the results of Hossain and Olasantan (2001), where pod length and pod diameter significantly reduced at closer intra row spacing in okra. But, the result of this study contradicts with the findings of Ali (1999) who stated highest pod length and pod weight at the closest plant spacing (50 cm x 25 cm) than the widest plant spacing (75 cm x 50 cm). On the other hand, Randhawa and Pannum (2000) declared pod length and pod diameter of okra were not significantly affected by the intra row spacing (45 cm x 25 cm and 45 cm x 30 cm) employed. These conflicting results might be due to the differences in the environmental pattern of the study locations and to the variation in the genetic potential of the cultivars/varieties used.

Green pod diameter

Green pod diameter was significantly affected by both inter-and intra-row spacing treatments whereas it was not significantly affected by the interactions of the two factors. Inter row spacing of 75 cm and 30 cm produced the biggest and smallest pod diameter of 31.18 mm and 25.85 mm, respectively. Likewise, pods obtained from inter row spacing at 60 cm were similar with those at 75 cm, (Table 5).

Regarding the effect of intra row spacing, the largest (30.40 mm) and smallest (26.14 mm) green pod diameters were also recorded in the widest (30 cm) and closest (15 cm) spacing, respectively. Plants spaced at 15 cm had pod diameter significantly lower compared to plants at the intra row spacing of 20 cm, 25 cm and 30 cm. In general, the result showed that pod diameter decreased with the reduction in both inter-and intra-row spacing. Pod diameter is one of the major criteria to judge okra yield and preferable pod size; bigger and longer green pods are the preferred and market appealing characters of okra (Moniruzzaman *et al*, 2007). In general, the bigger the diameter and the longer the pod size, the higher the yield obtained. The result revealed that the green pod yield per plant is directly related to the pod size (length and diameter). The spacing treatment combinations that produced the longest and biggest size pods recorded the highest green pod yield per plant.

Table 5. Main effect of inter-and intra-row spacing on green pod length, pod diameter and pod weight of okra at Humera, northern Ethiopia

Treatments	Pod length (cm)	Pod diameter (mm)	Pod weight (g pod^{-1})
Inter row spacing(cm)			
30	12.09^{c}	27.88^{c}	25.53^{d}
45	13.36^{b}	29.90^{bc}	27.70^{c}
60	14.16^{ab}	31.39^{ab}	29.84^{b}
75	14.66^{a}	33.29^{a}	30.70^{a}
Intra row spacing(cm)			
15	11.67^{b}	28.12^{b}	25.93^{b}
20	13.63^{a}	30.21^{ab}	28.28^{ab}
25	14.24^{a}	31.61^{a}	29.62^{a}
30	14.72^{a}	32.51^{a}	29.93^{a}
CV (%)	7.31	9.86	7.94

Means within a column for a parameter sharing common letter(s) are not significantly different at 5% probability level according to Tukey's Studentized Range (HSD) test; CV= coefficient of variation

This result agreed with the findings of Odeleye *et al*. (2005), Katung (2007) and Okunowo (2012), where pod length and pod diameter significantly reduced at closer row and plant spacing than at wider ones in okra. Similar observation was made by Ekwu and Nwokwu (2012) who reported that the lowest plant density of okra (37000 plants ha^{-1}) (50 cm x 75 cm) resulted in highest weight and diameter of pods per plant than the closest spacing (50 cm x 25 cm) suggesting that there was less competition for nutrient and space among the plants. Apart from this, Randhawa and Pannum (2000) declared non-significant effect of spacing on pod length and pod diameter of okra.

Green pod weight

Statistical analysis of data revealed significant differences among the various inter-and intra-row spacings for average weight of single green pod (Table 5). However, the green pod weight was not affected by their interactions. Maximum green pod weight (24.48 g and 24.01 g) were recorded in inter row spacing of 75 cm and in intra row spacing of 30 cm, respectively. Whereas, the minimum green pod weight was noted in inter-and intra-row spacing of 30 cm (20.20 g) and 15 cm (20.30 g), respectively. Statistical significant difference was obtained between inter row spacing of 30 cm and 75 cm while only intra row spacing of 15 cm was significantly different with that of 30 cm. This result was in agreement with the findings of Lee *et al*. (2001) and Moniruzzaman *et al*. (2007) who recorded the highest pod weight (27 g) at wider plant spacing of okra. Other findings reported by previous workers (Aiyelaagbe and Ogbonnaya, 1996; Singh, 1996; Olasantan, 2001; Hermann and Singh, 2003 and Lyon *et al*., 2010) also showed that wider spacing leads to heavier individual pod weight in okra. Similarly, Muhammad *et al*. (2001) recorded the highest and lowest pod weight per plant at the lowest and highest planting density of okra, respectively. In addition, Tesfaye (2005) found higher fruit weight of tomatoes at wider spacing (100 cm x 30 cm) as compared to the closer spacing (60 cm x 45 cm). Similar report was also reported by Mohammad *et al*. (2012) where greatest weight and volume of sweet pepper were recorded from plants in wider planting densities. Warner (2003), however, did not observe any significant influence of spacing on average fruit weight of both determinate and indeterminate types of tomatoes. This highest mean pod weight at the lowest planting density might be attributed to more nutrient and moisture availability for better vegetative growth in widest spacing, providing sufficient assimilate for the development of pods, ultimately resulting in higher pod weight.

Green pod yield per plant

Green pod yield of okra per plant was significantly affected by the main effects of inter row spacing and intra row spacing plus by their interaction effect (Table 6). Green pod yield per plant significantly increased with the decrease in plant population density (wider inter-and intra-row spacing) while an increase of plant population (closer spacing) resulted in low green pod yield per plant (Table 6). The highest green pod yield per plant (0.69 kg) was recorded from 75 cm × 30 cm, which was statistically at par with those at 75 cm × 25 cm, 75 cm x 20 cm and 60 cm × 30 cm spacing combinations but differed from the remaining treatments. On the other hand, the lowest green pod yield per plant (0.36 kg) was exhibited by 30 cm × 15 cm treatment combination, being statistically not significant with those at 30 cm × 20 cm, 25 and 30 cm, 45 cm x 15 cm, 60 cm x 15 cm and 75 cm x 15 cm.

With wider spacing, plants receive more growth factors which enhance lateral growth of the plants, resulting in more number of branches and pods plant^{-1} and increased pod length, diameter and weight, which ultimately results in higher green pod yield plant^{-1}. The yield of green pods increased with increase in number of green pods harvested, green pod length, diameter and pod weight. As these parameters were highest in wider spacing, therefore, green pod yield plant^{-1} was also highest in wider spacing. This indicates that the significant differences among the means were due to the interaction effect of the two factors (inter-and intra-row spacing) on the plant and pod growth characters. A number of similar findings have been reported by Malik and Mondal (1996); Siemonsma (1998); Gupta and Shukla (2000); Whitehead and Singh (2000); Albregts and Howard (2002) and Hermann and Singh (2003). In the same way, Aiyelaagbe and Ogbonnaya (1996); Abdul (1999); Absar and Siddlque (2001); Lee *et al*. (2001); Cushman *et al*. (2005) and Smith and Ojo (2006) observed that green pod yield per plant was reduced as plant population density of okra increased. Moreover, from the investigation of the influence of plant population on the productivity of green pepper (*Capsicum annuum* L.) by Cavero (2001), using different plant populations (50 000, 62 500, 83 333, 100 000, 111 111, 160 000 and 200 000 plants ha^{-1}), fruit number and yield per plant decreased when plant population increased from 50 000 to 200 000 plants ha^{-1}. In comparison, this study revealed a continual increase in green pod yield plant^{-1} from the highest (22.2 plants m^{-2}) (0.36 Kg plant^{-1}) to the lowest density (4.4 plants m^{-2}) (0.69 Kg plant^{-1}).

Table 6. Interaction effect of inter-and intra-row spacing on green pod yield of okra at Humera, northern Ethiopia

Spacing (cm)		Green pod yield	
Inter-row	Intra-row	(kg plant^{-1})	(t ha^{-1})
30	15	0.41^{f}	18.24^{f}
30	20	0.44^{ef}	18.92^{ef}
30	25	0.44^{ef}	18.92^{ef}
30	30	0.50^{d}	20.12^{e}
45	15	0.46^{de}	19.03^{ef}
45	20	0.57^{c}	22.90^{bc}
45	25	0.58^{c}	24.51^{a}
45	30	0.58^{c}	23.77^{ab}
60	15	0.49^{d}	19.46^{e}
60	20	0.58^{c}	22.82^{bc}
60	25	0.59^{bc}	22.20^{cd}
60	30	0.63^{ab}	21.54^{d}
75	15	0.51^{d}	19.58^{e}
75	20	0.60^{bc}	21.82^{cd}
75	25	0.63^{ab}	21.53^{d}
75	30	0.66^{a}	21.42^{d}
CV (%)		3.29	4.56

Means within a column for a parameter sharing common letter(s) are not significantly different at 5% probability level according to Tukey's Studentized Range (HSD) test; CV= coefficient of variation

Green pod yield per hectare

All the three sources of variation, i.e. inter row spacing, intra row spacing, and their interaction significantly affected green pod yield ha^{-1} (Table 6). As the different plant characters of okra were greatly affected by the main factors and by their pair of interactions, the pod yield ha^{-1} was also affected. The highest green pod yield ha^{-1} (20.65 t) was obtained from the treatment combination of 45 cm x 25 cm, which was statistically similar with those at 45 cm x 30 cm. However, the lowest green pod yield per hectare (12.86 t) was obtained from the treatment combination of 30 cm x 15 cm, which was statistically at par with those at the inter-and intra-row spacing combinations of 30 cm x 20 cm, 25 cm and 30 cm, 45 cm x 15 cm, 60 cm x 15 cm, 25 cm and 30 cm and 75 cm x 15 cm, 20 cm, 25 cm and 30 cm (Table 6).

The final yield of a crop is the expression of combined effect of various yield components. Likewise, pod yield of okra is the ultimate product of different yield contributing characters, such as number of branches, number of pods and yield per plant, pod length, pod weight and pod diameter (Hossain and Olasantan , 2001). Green pod yield of okra ha^{-1} depends upon the yield plant^{-1} and plant population. So, closer spacing up to a certain limit results in higher pod yield ha^{-1} due to more number of plants, whereas wider spacing leads to less number of plants ha^{-1} and ultimately low yield. Increased yields at higher population densities have also been reported in other vegetable crops (Nasto *et al*., 2009). Tesfaye (2005) reported the highest total and marketable fruit yield ha^{-1} of tomato at closer spacing (80 cm x 30 cm) than at wider spacing (100 cm x 30 cm). The highest total and marketable fruit yield of tomato cultivars at closer spacing could be due to the higher plant population ha^{-1} at closer spacing than at wider spacing, and the closer spacing might have enabled maximum use of nutrients better than the wider spacing as has been suggested by the author. Yield ha^{-1} also increased as plant density increases in sweet pepper (Mohammad *et al*., 2012). Here, the highest density (50 cm × 20 cm) produced the highest fruit yield (147190 kg ha^{-1}) while the lowest yield ha^{-1} (49130 kg ha^{-1}) was recorded at spacing of 100 cm × 30 cm. This total yield increment with higher planting densities is probably due to increase in the number of plants per unit area, which might have contributed to the production of extra yield per unit area, leading to high yield. Cavero (2001) also reported that marketable fruit yield of green pepper increased as plant population increased from 50 000 to 200 000 plants ha^{-1} and slightly decreased with a further increase in plant population. The increase in fruit yield ha^{-1} as a result of increased plant population to a threshold level could be attributed to a better utilization of available natural growth resources.

Contrary to the data of pod yield on a per plant basis, green pod yield on an area basis (yield ha^{-1}) was highest at 45 cm x 25 cm and 45 cm x 30 cm pair of combinations; beyond this row and plant spacing, decreasing trend in yield ha^{-1} was observed. Therefore, the three year study revealed that spacing combinations of 45 cm x 25 cm or 45 cm x 30 cm could be regarded as the appropriate inter-and intra-row spacing for optimum yield of okra in the pilot area. Earlier studies on okra plant population density have reported increases in crop productivity as density increased to 10 plants m^{-2} (Siemonsma, 1998). Whitehead and Singh (2000) also revealed a continuous increase in pod yield of okra from the lowest (2.4 plants m^{-2}) to the highest density (14 plants m^{-2}). Singh (1996) proposed that the yield response of okra to increased plant populations would saturate between 10 and 20 plants m^{-2} due to inter-plant competition and floral abortion. Besides, Abdul (1999) observed progressive yield reduction up to 0.5 t ha^{-1} for each reduced intra row spacing from 30 cm. However, Hermann and Singh **(**2003) observed no difference in okra yield at spacing of 4, 8, or 16 plants m^{-2}. Similarly, Okunowo (2012) reported non-significant effect of spacing in yield of okra planted at 100 cm x 25 cm; 90 cm x 30 cm; 60 cm x 40 cm and 50 cm x 50 cm spacing combinations.

In comparison, our study revealed a continual increase in pod yield ha^{-1} from the lowest, 75 cm x 30 cm (4.4 plants m^{-2}) to the highest density of 45 cm x 25 cm (11.1 plants m^{-2}). However, Albregts and Howard (2002) observed okra increases in yield up to 64 plants m^{-2}. These conflicting results could be caused due to the variation in the environment where the trials have been carried out and differences in the genetic potential of the varieties/cultivars used. Therefore, our three year study emphasizes that an acceptable plant population density or what constitutes a “good” stand will vary with location, environmental conditions, cultivar, and grower preference.

4.4. Correlation Matrix

To know the extent of relationship between yield and its various components, correlation matrix was performed for all the data collected (Table 7). From the result observed in this study, it was interesting to note that most of the parameters measured showed highly significant positive or negative correlations with green pod yield plant^{-1} and ha^{-1}. Green pod yield plant^{-1} was positively and significantly correlated with all parameters measured with the exception of plant height, which was significantly but negatively correlated. Green pod yield ha^{-1} was negatively and significantly correlated with plant height at 15 and 30 DAE and with LAI, and negatively but not significantly with plant height at flowering and that of last picking. This is an indication that these parameters are more related and hence affect okra yield directly. For instance, plant height was significantly and negatively correlated with all parameters measured; suggesting that any increase in this parameter will induce a reduction in the value of other parameters. However, some previous results indicate that plant height had positive correlation with number of branches in okra (Saha *et al*, 2005).

On the other hand, both days to 50% flowering and pod setting had a significant positive relationship with all parameters excluding plant height and leaf area per plant. This suggests that any increase in days to flowering and/or pod setting will lead to corresponding increase in these parameters; say for instance yield. The parameters which were positively correlated with yield were also positively correlated among themselves. Thus, this explains in depth that yield can be improved considerably through selecting parameters like number of branches and pods per plant, length of pod-bearing zone, pod length, diameter and weight and yield per plant and the like. Both number of leaves per plant and LAI had also exerted significant positive and negative direct effect on yield increment, respectively.

In general, green pod yield ha^{-1} was not significantly correlated with plant height both at flowering and at last picking. This result contradicts with the report of Malik and Mondal (1996) that indicate height at flowering and at final harvest are vegetative traits that are important for yield determination in okra. There existed a linear relationship between green pod yield plant^{-1} and row and plant spacing. The progressive increase in yield with row and plant spacing occurred due reduction in the competition for growth factors as the space increased. But, for green pod yield ha^{-1} (on a unit area basis), this relation was parallel up to a certain spacing combinations. The upper yield limit was attained at 45 cm x 25 cm spacing combination followed by 45 cm x 30 cm. This can be explained as the spacing at which optimum green pod yield per unit area can be expected. Further increase or decrease in plant population by planting at less than 45 cm x 25 cm or more than 45 cm x 30 cm gave lower green pod yield ha^{-1} due to sever plant competition and improper resource utilization, respectively.

Table 7. Correlation matrix comparisons for phenological, growth and yield parameters of okra at 5% level of significance

	H15	H30	Hflo	Hlas	NL15	NL30	NLflo	LAI15	LAI30	LAIflo	DF	DP	Br/pla	LPBZ	Po/pla	PL	PW	PD	PY/pla	PY/ha
H15	1.00	0.52*	0.20	0.27	-0.35*	-0.28	-0.28	0.37*	0.48*	0.48*	-0.53*	-0.17	-0.41*	-0.44	-0.35*	-0.50*	-0.22	-0.21	-0.38*	-0.32*
H30		1.00	0.32*	0.39*	-0.12	-0.32*	-0.11	0.59*	0.66*	0.67*	-0.21	-0.46*	-0.45*	-0.41*	-0.38*	-0.64*	-0.54*	-0.55*	-0.54*	-0.30*
Hflo			1.00	0.97*	-0.54*	-0.13	-0.56*	0.56*	0.59*	0.59*	-0.19	-0.27	-0.42*	-0.52*	-0.45*	-0.44*	-0.52*	-0.54*	-0.65*	-0.13
Hlas				1.00	-0.53*	-0.19	-0.58*	0.61*	0.64*	0.65*	-0.23	-0.35*	-0.48*	-0.57*	-0.49*	-0.49*	-0.60*	-0.53*	-0.69*	-0.19
NL15					1.00	-0.02	0.62*	-0.31*	-0.40*	-0.40*	0.40*	0.05	0.37*	0.55*	0.53*	0.42*	0.31*	0.33*	0.46*	0.11
NL30						1.00	0.53*	-0.30*	-0.32*	-0.30*	0.31*	0.42*	0.53*	0.50*	0.56*	0.39*	0.28	0.16	0.40*	0.73*
NLflo							1.00	-0.37*	-0.47*	-0.44*	0.45*	0.24	0.65*	0.77*	0.78*	0.45*	0.41*	0.36*	0.59*	0.61*
LAI15								1.00	-0.45*	0.56*	-0.30*	-0.72*	-0.79*	-0.69*	-0.63*	-0.79*	-0.72*	-0.54*	0.89*	-0.50*
LAI30									1.00	0.89*	-0.47*	-0.65*	-0.86*	-0.77*	-0.71*	-0.83*	-0.76*	-0.65*	0.90*	-0.53*
LAIflo										1.00	-0.46*	-0.63*	-0.83*	-0.76*	-0.69*	-0.83*	-0.75*	-0.63*	0.88*	-0.50*
DF											1.00	0.17	0.48*	0.47*	0.46*	0.45*	0.20	0.33*	0.44*	0.35*
DP												1.00	0.63*	0.43*	0.46*	0.62*	0.58*	0.46*	0.65*	0.4*9
Br/pla													1.00	0.88*	0.85*	0.78*	0.73*	0.54*	0.89*	0.78*
LPBZ														1.00	0.91*	0.74*	0.63*	0.49*	0.79*	0.70*
Po/pla															1.00	0.70*	0.61*	0.52*	0.75*	0.74*
PL																1.00	0.69*	0.63*	0.81*	0.54*
PW																	1.00	0.55*	0.78*	0.48*
PD																		1.00	0.67*	0.21
PY/pla																			1.00	0.59*
PY/ha																				1.00

DAE=days after emergence; LAI=leaf area index; H15= plant height at 15 DAE; H30= plant height at 30DAE; Hflo= plant height at flowering; Hlas= plant height at last picking; NL15=number of leaves per plant at 15 DAE; NL30= number of leaves per plant at 30 DAE; NLflo= number of leaves per plant at flowering; LAI15=LAI at 15 DAE; LAI30= LAI at 30 DAE; LAIflo= leaf area per plant at flowering; DF=days to flowering; DP= days to pod setting; PL=green pod length; PW= green pod weight; PD= length of green pod; LPBZ=length of pod-bearing zone; Br/pla=branches per plant; Po/pla=number of pods per plant; PY/pla= green pod yield per plant and PY/ha= green pod yield/ha

5. SUMMARY AND CONCLUSION

Sustaining yield and productivity in intensive cropping systems for higher yields and better quality can be achieved by fully exploiting the potential or biological yield of a crop at hand. However, this is only possible through improved crop management practices and varietal development. Thus, reliable information on agronomic management practices such as appropriate row and plant spacing and crop response to this row and plant spacing and/or plant population density is quite important to come up with profitable and sustainable crop production and productivity. In line with this, field research was undertaken to investigate the effect of inter-and intra-row spacing on growth and yield of okra at Humera, northern Ethiopia, for three years (from 2012 to 2014 main cropping seasons). Four levels of inter row spacing (30, 45, 60 and 75 cm) and four levels of intra row spacing (15, 20, 25 and 30 cm) were adopted as treatments with three replications in factorial arrangement using randomized complete block design.

The main effects of inter-and intra-row spacing were significant ($p < 0.05$) both on plant height and number of leaves per plant at 15 and 30 DAE, LAI at 15 DAE, days to flowering and pod setting, green pod length, diameter and weight. With the exception of plant height and LAI, the aforementioned parameters were found to increase consistently with increasing both row and plant spacing while the reverse also holds true.

Parameters like plant height at flowering and at last picking, number of leaves per plant at flowering, LAI at 30 DAE and at flowering, length of pod bearing zone, number of branches per plant, number of green pods per plant, and green pod yield plant^{-1} and ha^{-1} were significantly affected by main effects and by the interactions of the different row and plant spacing combinations.

The means of interaction (inter row spacing x intra row spacing) revealed that the plants grown on wider spacing (75 cm x 30 cm) resulted in the highest green pod yield plant^{-1} (0.66 Kg), being statistically at par with that of 75 cm x 30 cm, 75 cm x 27 cm, 65 cm x 30 cm spacing.

Regarding the yield on an area basis, the highest green pod yield per hectare (24.51 t) was obtained when plants spaced moderately closely (45 cm x 25 cm, being non-significant with 45 cm x 30 cm). This implies that green pod yield per unit area can be maximized with closer spacing, but green pod yield plant^{-1} and quality parameters like length, weight and diameter of individual pod can be improved with wider spacing. So, this suggests the need to compromise between optimum yield and quality when selecting appropriate inter-and intra-row spacing in okra.

Results of the correlation matrix showed that the adopted inter-and intra-row spacing levels were associated positively with most of the parameters studied. Yield and yield parameters were positively and significantly correlated with all parameters measured except plant height and LAI. Thus, it is evident that yield can be improved considerably through selecting parameters like number of pods per plant, pod weight, pod diameter, pod length, yield per plant, length of pod bearing zone, and number of branches and pods per plant and the like, by adopting proper inter-and intra-row spacing. Therefore, the result of the present study can serve as a guiding index in generating proper plant population density for obtaining higher yield and good quality of green pods in okra.

In general, the study revealed a continual increase in green pod yield ha^{-1} from the lowest, 75 cm x 30 cm (4.4 plants m^{-2}) to the highest density of 45 cm x 25 cm (11.1 plants m^{-2}). Due to optimization of inter-and intra-row spacing, a yield improvement of 34.4% from the closest spacing (30 cm x 15 cm) and 14.4% from the widest spacing (75 cm x 30 cm) was obtained. Therefore, it can be concluded that inter row spacing of 45 cm and intra row spacing of 25-30 cm as the best pair of spacing (appropriate inter-and intra-row spacing) that optimum green pod yield of okra can be expected in Humera area.

Since this study was the first of its kind in the country, research concerning all other pre-and post-harvest crop management practices along the variability study (varietal screening) should be undertaken to improve production and productivity of the crop at a national level. It would also be logical to promote the production of the crop to contribute its part in alleviating the malnutrition and poverty for the ever-increasing population.

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