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Yield and Yield Components of Pigeon pea (*Cajanuscajan*(L.) Millsp) as Affected by Planting Density

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Abstract : A field experiment was carried out to examine the effect of population density on yield, yield components, and associated parameters of two pigeon pea (*Cajanuscajan*) varieties. The treatment consisted of two varieties of viz. ICPL 87091 and ICP 15027 with determinate and indeterminate growth habits, respectively, and five planting densities viz., 166666, 200000, 250000, 333333 and 500000 plants ha^{-1}. A split-plot design with variety as the main plot factor and population density as sub-plot factor were used, and the treatments were replicated thrice. Results showed no significant difference in grain yield and aboveground biomass yield ha^{-1} between the two varieties while a significant difference was observed in yield components (branches per plant, pod per plant, seed per pod, and 100-seed weight). The effect of plant density on grain and aboveground biomass yields were significant ($P < 0.05$) and the higher plant densities (i.e., 500000 and 333333 plants ha^{-1}) produced higher grain yield (i.e., 3.78 and 3.5 t ha^{-1}, respectively) than the lower plant densities (i.e., 250000, 200000 and 166666 plants ha^{-1}). While total biomass increased with increasing population density with the highest (19.00t ha^{-1}) and the lowest (9.17 t ha^{-1}) biomass were obtained at the highest (500000 plants ha^{-1}) and the lowest population density (166666 plants ha^{-1}), respectively. The observed higher productivity under increasing population density was related to the positive (enhancing) effect of population density on yield components and leaf area index (LAI).The parameters including a leaf area, pod number, dry matter, and branch number per plant have decreased with increasing population density and this was the reverse of what has been observed for these parameters on per unit area basis. Because of the absence of significant difference for grain yield between the two the upper most densities, ease of management, the economy of seed, and lower labor cost, a density of 333333 plant ha^{-1} could be preferred to be used in the test area.

Keywords: *pigeon pea, planting density, variety, yield, yield components*.

1. Introduction

Pigeon pea (*Cajanuscajan* (L.) Millsp) is an important grain legume crop grown in tropical and subtropical regions (Wilson *et al*., 2012), and well-adapted in arid and semi-arid climate (Rao*et al*., 2003; Raju*et al*., 2010). It can perform well in degraded soil and in regions where moisture availability is unreliable and inadequate (Reddy *et al*., 1993). Because of its multiple uses as a source of food, feed, fuel, and fertilizer (Wilson *et al*., 2012), it finds an important place in the farming systems adopted by smallholder farmers (Saxena*et al.*, 2010).

Pigeon pea ranks sixth in importance among edible food legumes of the world (Varshney*et al*., 2011). In addition to its main use as dhal (dry, dehulled, split seed used for cooking), its tender green seeds are used as a vegetable, crushed dry seeds as animal feed, green leaves as fodder, stems as fuel wood and to make huts, baskets, etc. In Ethiopia, pigeon pea is used as any other legume in the forms of ‘*Nifro*’, ‘*Kikwat*’ ‘*Shiro*’ ‘, soup’ and so on. The nutritive value of pigeon pea is compared favorably with

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other food legumes (Amarteifioet al., 2002). Pigeon pea is an excellent source of proteins (20–30%) (Snapp *et al*., 2003), which is about three times the value found in cereals. The protein is also of excellent quality, being high in lysine (ICRISAT, 1991). The crop is, therefore, an important complement to cereals (Saxena*et al*. 2010).

Biological N fixation is important for smallholder farmers as it is a relatively cheaper source of N compared to inorganic fertilizers, less prone to losses through leaching and denitrification (Mhango*et al*., 2017). Pigeon pea can fix 69 to 100 kg N ha^{-1} (Kumar Rao*et al*., 1987), and 30 and 53 kg ha^{-1} in a dry and wet season, respectively (Mhango*et al*.,2017). Pigeon pea grows well in the phosphorus-deficient soils of the tropical environment (Fujita *et al*., 2004). The crop is deep-rooted, so their ability to release more phosphates means that valuable nutrients are being brought up from the deeper soil layers (Saxena*et al*., 2010). Moreover, the release of the nutrients benefits the subsequent crops grown in the same field. The crop is also grown in the hilly tracts for soil conservation because of its deep tap root system and canopy development (Saxena*et al*., 2010). As a result, there is interest in the cultivation of this crop in non-traditional areas because of its beneficial effects on soil fertility and organic matter (Whitbread *et al*., 1999).

Pigeon pea is grown in Africa (FAOSTAT, 2007), particularly in East Africa countries such as in Tanzania, Kenya, and with little production in Ethiopia (Karanja, 2016). However, medium and late maturing pigeon pea cultivars are used in Africa (Sakala*et al*., 2000), which are low in yield (Mergeai*et al*., 2001). The average yield of pigeon pea in Africa is 718 kg ha^{-1} (±171) and the maximum recorded yield (1087 kg ha^{-1}) (FAOSTAT, 2007). ICRISAT in collaboration with different Agricultural Research Centers in Africa has developed improved early maturing pigeon pea varieties (Omanga*et al*., 1995; Jones *et al*., 2001). The Ethiopian Institute of Agricultural Research, particularly Melkassa Agricultural Research Center is working on early pigeon pea (potential in grain yield) (FAO, 2010) as one of the lowland grain legumes under its mandate. These short-duration types are used as mono-crop in rainfed areas (Saxena*et al*., 2010). The identified promising cultivars showed a remarkable increase in yield ranging 2 t ha^{-1} to 4 t ha^{-1} (Saxena*et al*., 2010).

The productivity of pigeon pea can be increased through different agronomic manipulations (Mallikarjun*et al*., 2014). Population density is one of the important agronomic factors affecting plant development, growth, and yield of crops (Hassan and Khaliq, 2008; Islam *et al*., 2008; McRae *et al*., 2008). Maintaining the optimum density is very important to exploit maximum natural resources such as nutrients, sunlight, soil moisture, and for achieving high yield (Sharifi*et al*., 2009). To realize the potential of the crop and to meet the ever-growing demand of the country for food, application of the proper agronomic technology such as optimum plant population density would be crucial. However, valuable information such as the response of pigeon pea varieties of varying growth habits to population density is scanty and limited. This study was therefore, initiated with the objective to assess the response of pigeon pea varieties to different population densities andidentify the optimum population density that could enable us achieve a higher grain yield of pigeon pea in the study area.

2. Materials and Methods

2.1. Experimental Site

An experiment was carried out at the research field of Hawassa Agricultural Research Center during the 2006 cropping season. The experimental site is located in Hawassa district, South Nations, Nationalities and Peoples Regions of Ethiopia, about 275 km from Addis Ababa. The site lies 7^{o} 04' N latitude and 38^{o} 31' E longitude, and at an altitude of 1660 meters above sea level. The soil type at the experimental site is Fluvisol largely developed from volcanic parent material based on the FAO/UNESC soil classification system (AARC, 2004). The soil texture was sandy clay loam with of pH of 6.75, the total N of 0.056 %, available phosphorous of 63.65 ppm, and organic carbon of 1.76 % (Meseret, 2006). The average annual rainfall of the area for the last 15 years was 1100 mm with a range of 674-1365 mm, while the average annual minimum and maximum temperatures were 12 °C and 27 °C, respectively (NMA, 2006).

2.2. Treatments and Experimental Design

Treatments consisted of five planting densities (166666,200000, 250000,333333 and 500000 plants ha^{-1}) as sub-plots and two pigeon pea varieties (ICPL 87091 and ICP 15027) as main plot factors. The five densities were obtained by adjusting the inter-row spacing while keeping the intra-row spacing similar at 10cm. The inter-row spacing for the five densities from the highest to the lowest were 60, 50, 40, 30, and 20 cm, respectively. The experiment was laid out in a split plot design and treatments were replicated three times.

The two varieties differ in their morphological characters: variety ICPL 87091 has determinate growth habit with erect plant type and cream-colored seed, whereas variety ICP 15027 has indeterminate growth habit with semi spreading plant type and reddish-brown seeds. Both varieties grouped under the early maturing group with a growth duration of 120 days (ICRISAT-Kenya, 2001).

2.3. Crop Management

The land for the experiment was prepared in June 2006 and the plant seed was sown on the 8th of July 2006. Phosphorus and Nitrogen fertilizers were applied in the form of Diammonium phosphate (DAP) at 100 kg ha^{-1} to give 18 kg N and 20 kg P ha^{-1} during sowing. Due to the incidence of pod borer insects in the experimental field, synthetic insecticide, lambda-cyhalothrin (Karate ^{T} 17.5 EC) (Zeneca Ltd., Fernhurst, Haslemere, UK), with the commercial formulation containing 17.5 g a.i., was applied at the recommended rate of 1 lit ha^{-1}. The insecticide chemical was applied using CP15^{T} Knapsack sprayer (Cooper Pegler, Sussex, UK). Spray applications were done twice, at the start of flowering and 15 days after the first spray. Three times hand weeding was carried out at 30 days interval starting from 30 days after sowing (DAS). All other necessary cultural practices were accomplished manually as required, during the growing period.

2.4. Data Collection

Days to emergence were recorded as the number of days from sowing to 50 percent emergence. Days to flowering were taken as the number of days from emergence to 50 percent first flower production. Days to maturity were recorded when 75 percent of the pods in a plot turned brown.

Starting from 30 days after sowing (DAS), samples of four plants from each plot were taken to determine crop growth parameters such as plant height, leaf area, and dry matter. Sampling continued for nine sequential harvestings at two-weeks interval up to the final harvest. Plant height was measured taking the length from plant base to the tip of the main stem. Leaf area was measured using a leaf area meter (model LI-3000A Li-Cor, Lincoln) at every sampling by a destructive method. The LAI was computed as a ratio of leaf area of plants to the ground area occupied by the sample plants. Dry matter was determined by drying the above the ground parts of the four sampled plants at 70 °C for 48 hours in a forced air ventilated oven.

Two central rows were harvested for determination of grain yield. Grain yield was adjusted to 12.5% moisture content. Five plants were randomly selected from each plot of the two central rows to determine yield components such as branches per plant, number of pods per plant, number of seeds per pod, and hundred seed weight.

The number of branches per plant was determined at crop physiological maturity. Pod number per plant and unit area was determined by taking pods of the five randomly selected plants. The number of seeds per pod was recorded by counting the total number of seeds in a pod from ten randomly sampled pods taken from the five randomly selected plants. Hundred seed weight was determined by counting a sample of seeds from each plot and weighted using sensitive balance. The harvest index was calculated as the ratio of seed yield to total above the ground biomass yield.

2.5. Data analysis

Data were subjected to analysis of variance (ANOVA***)*** using SAS software (SAS version 6.12, 1997). Mean separation was performed using LSD at 0.05 level of probability (Gomez and Gomez, 1984).

3. Results and Discussion

3.1. Weather and Physiochemical Properties of the Experimental Soil

The experiment was conducted during the main cropping season (July to December, 2006) under rain-fed condition. The amount of rainfall for the crop growth duration was 654.7 mm and the annual rainfall was 1197.9 mm. During the cropping period, the mean temperature was 19.8°c with the mean minimum and maximum temperatures of 14.0°C and 25.7 °C, respectively (Fig 1). Pigeon pea grows in areas with inadequate moisture availability like areas receiving annual rainfall less than 1000 mm (Okoko*et al.*, 2002). It implies the rainfall pattern and the temperature of the research site during the growing period was suitable for pigeon pea growth.

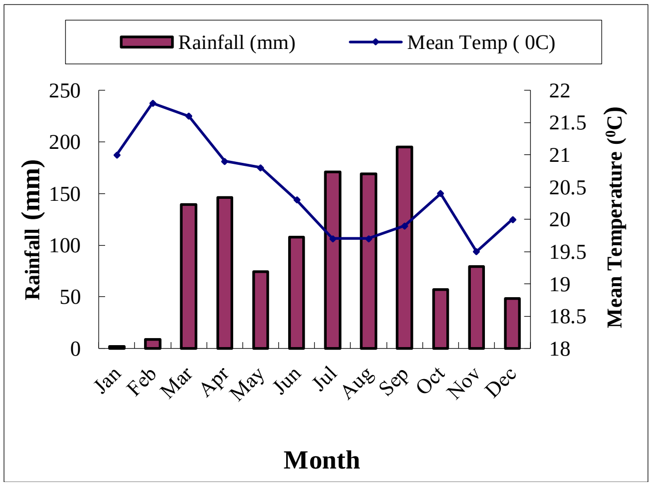

Figure 1: Monthly rainfall and Mean temperature at Hawassa, in 2006. Crop growth period was from July 8 to December 18

The soil analytical results indicate a pH value of 6.75 (neutral). Most crops grow well in optimum pH ranges from 4 to 8 (FAO, 2000). For optimum results, pigeon pea requires deep loam and almost neutral soils (Dalal and Quilt, 1977). As a result, the soil pH of the experimental site was suitable for pigeon pea production. The soil texture was sandy clay loam and contains total N of 0.056 % which falls in the low range (< 0.1%), available phosphorous of 63.65 ppm which falls in a high range (> 25 ppm) and organic carbon of 1.76 % which is in the low range (< 4 %) (Landon, 1991). Growing pigeon pea is recommended in the area because the crop plays an important role in increasing N content of the soil by fixing atmospheric nitrogen (Kumar Rao*et al.*, 1987, Mhango*et al.*, 2017), and has beneficial effects on soil fertility and organic matter (Whitbread *et al.*, 1999).

3.2. Effect of planting density on phenology and growth of pigeon pea varieties

The result indicates that neither variety nor plant density has significant effect on days to 50% emergence and 50%

flowering (Table 1). The result corroborates with the findings of Meseret (2006) who reported the non-significant effect of population density on days to emergence and flowering of mung bean. Days to 75% maturity was significantly influenced by variety (Table 1). The determinate variety (ICPL 87091) matured earlier (158 days) than the indeterminate variety (ICP 15027) that took 164 days (Table 2). The possible reason for the differences in maturity between the two varieties might be variation in growth habits, indeterminate plants produce flowers and grow taller throughout the growing season whereas this is not possible in case of determinate genotypes (Sapkal*et al.*, 2015). The late-maturing beans were more often indeterminate while those of the early ones were determinate (Kelly, *et al.*, 1987). Moreover, the temperature in the growing season might have contributed to the variation in the date of maturity on the two varieties. Increasing temperature, in the range of 20-30 ^{o} C, affects some morphological and physiological characteristics of crops (Squire, 1990). As the temperature increases in the range of 20-30 ^{o} C, duration from full canopy development to harvest decreases in determinate and increases in indeterminate crops (Squire, 1990). According to meteorological data obtained (Fig 1), the monthly mean temperature during the cropping period was in the range of 19.7 ^{o} C and 20.4 ^{o} C which might contribute for earlier maturity of the determinate variety (ICPL 87091) and late maturity of the indeterminate variety (ICP 15027). Days to maturity of both varieties were extended to a maximum of 164 days though both varieties were expected to mature within 120 days according to ICRISAT-Kenya (2001). This happened because of the extension of the rainy season (Fig 1), which led to higher plant water status that might have delayed the maturity (Felix, 2009; Deshmukh and Mate,2013) and enhanced vegetative growth.

Table 1:. Mean square values for phenology and growth characters of pigeon pea as affected by varieties and population densities

		Mean squares					
Source	DF	Days to 50% emergence	Days to 50% flowering	Days to 75% maturity	Plant height	Dry matter plant^{-1}	Dry matter m^{-2}area
Replication	2	2.10	14.23	20.23	10.68	357.43**	8737.44
V (variety)	1	0.83	3.33	235.20*	1557.51**	108.53	3571.93
Error a	2	0.23	15.23	6.10	5.63	38.44	4622.12
D (density)	4	0.13	1.45	1.88	61.69*	698.52***	104397.03***
V * D	4	0.17	9.58	34.78	53.79	0.68	2541.43
Error b	16	0.13	11.44	15.71	18.01	46.27	5196.84

*, **, ***, Significant at 0.05, 0.01 and 0.001 P-levels, respectively

The indeterminate variety (ICP 15027) was taller than the determinate variety (ICPL 87091) with their respective mean heights of 92.8 cm and 78.4 cm (Table 2). Indeterminate plants produce flowers throughout the growing season whenever sufficient moisture is available. This is not possible in the case of determinate genotypes (Sapkal*et al.*, 2015). Moreover, most of the vegetative growth during flowering and pod set occurred on branches on determinate types while it was on the main stem with indeterminate types (Egli*et al.*, 1985). Because of this growth habit, the two varieties must be administered with different crop management. The short stature of the determinate plant types make them amenable to efficient crop management practices, such as foliar insecticide application and mechanized crop production whereas, indeterminate plants, on the other hand, grow taller; hence, efficient management and mechanization become difficult (Sapkal *et al.*, 2015). The increase in plant density significantly decreased plant height and dry matter per plant (Table 2). The highest plant density of (500000 plants ha^{-1}) decreased the dry matter per plant by 55.46% compared to the lowest plant density (166666 plants ha^{-1}). These results are consistent with the works of Akinola and Whiteman (1974) who did related work on pigeon pea. At the lowest population density, there could be the utilization of resources with less competition compared to the higher population density. On the other hand, dry matter per unit area increased with increasing population density. The interception of more light per unit area might have contributed to the increment of dry matter per unit area under increasing population density.

The determinate variety (ICPL 87091) showed relatively higher leaf area per plant than the indeterminate variety (ICP 15027) in most samplings though the differences were significant only for three samplings (Table 3). On the other hand, variety ICP 15027 showed a tendency of increment of leaf area at the last two samplings (135 DAS and 150 DAS) that could be the indeterminate nature of the variety.In other words, the metabolites of indeterminate varieties partitioned more to vegetative parts (leaves) even at the pod filling stages. That might have resulted in old leaves of indeterminate varieties remain green for a longer time, before senescence than that of determinate ones. As a result, the leaf area of indeterminate variety became higher than that of determinate one.

Table 2:. The effect of population density and variety on crop phenology and growth characters of pigeon pea during 2006 cropping season

Treatments	Days to 50% emergence (days)	Days to 50% flowering (days)	Days to 75% maturity (days)	Plant height (cm)	Dry matter plant^{-1} (g)	Dry matter m^{-2} area (g)
Variety						
ICPL 87091	9.93	103.20	157.93b	78.35b	40.83	731.23
ICP 15027	10.27	103.87	163.53a	92.76a	37.03	709.41
LSD $_{0.05}$	NS	NS	3.88	3.73	NS	NS
Population density (Plants ha^{-1})						
166666	10.00	103.67	160.33	88.10a	51.17a	584.10c
200000	10.00	103.83	161.33	88.03a	46.01ab	628.84bc
250000	10.00	103.67	161.33	87.45ab	37.73bc	676.18b
333333	10.17	103.83	160.50	82.78bc	36.96c	812.82a
500000	10.33	102.67	160.17	81.40c	22.79d	899.68a
LSD$_{0.05}$	NS	NS	NS	5.19	8.33	88.23
CV %	3.50	3.27	2.47	4.96	17.47	10.01

Means with the same letter in a column in each category are not significantly different at $P < 0.05$, LSD (0.05) = least significant difference at 5% probability level, CV = coefficient of variation, and NS = non-significant difference.

The maximum leaf area obtained in both varieties was at 120 DAS that matched the expected days to maturity (120 days) of both varieties according to ICRISAT-Kenya (2001). An increase in plant density decreased the leaf area per plant (Table 3). This finding is in agreement with the result of Rowden*et al.* (1981) who reported that the leaf area of individual plants declines as the population density increases. The largest leaf area was obtained at 120 DAS across all population levels. The maximum leaf area (1604.3 cm^2) was observed at the lowest plant density of 166666 plants ha^{-1}. The minimum leaf area was recorded at the highest plant density that could be less light interception per plant with increasing plant density which resulted in reduced assimilation rate per plant compared to sparsely populated ones, which in turn limits the number of resources allocated for leaf development.

Table 3:.Leaf area per plant of pigeon pea at different growth stages as affected by varieties and population densities during 2006 cropping season

Treatments	Leaf area (cm^2) at different days after sowing								
	30	45	60	75	90	105	120	135	150
Variety									
ICPL 87091	13.29a	26.12	195.11	429.32	659.55	1201.05a	1248.13	707.63b	438.01
ICP 15027	12.01b	24.07	187.77	412.62	637.69	1046.56b	1196.60	872.35a	480.63
LSD$_{0.05}$	1.27	NS	NS	NS	NS	50.07	NS	113.73	NS
Population density(plants ha^{-1})									
166666	13.50ab	28.04a	208.12a	492.16a	787.32a	1476.28a	1604.33a	1137.36a	606.65a
200000	13.67a	27.46a	193.86b	467.62ab	696.38b	1285.10b	1412.43b	917.93b	552.33b
250000	12.49bc	24.51b	189.68bc	439.63b	631.02c	1124.40c	1191.09c	798.05c	471.41c
333333	11.87c	22.90b	188.31bc	378.19c	590.33cd	964.21d	1040.73d	638.55d	390.40d
500000	11.72c	22.55b	177.22c	327.26d	538.06d	769.05e	863.26e	458.05e	281.41e
LSD$_{0.05}$	1.10	2.56	13.09	40.81	62.20	126.75	114.06	92.01	41.10
CV%	7.09	8.35	5.59	7.92	7.84	9.22	7.62	9.52	7.31

Means with the same letter in a column in each category are not significantly different at $P < 0.05$, LSD (0.05) = least significant difference at 5% probability level, CV = coefficient of variation, and NS = non-significant difference

Leaf area index of the two varieties showed no significant difference except at 105 and 135 days after sowing (DAS) (Table 4).The maximum LAI of the determinate and indeterminate varieties were 3.3 and 3.2, respectively (Table 4). Maximum LAI was obtained at 120 DAS, which was the pod setting stage, in both varieties. Higher LAI and light interception coincide with the podding phase in pigeon pea (Patel *et al.*, 2000). The decrease in LAI at later growth stages could be due to leaf senescence, abscission, and ontogeny. Accelerated senescence during pod setting could be the result of the remobilization of the stored metabolites from the leaf to the developing pods (Biswas*et al.*, 2002). In the case of planting density, the maximum LAI (4.32) was recorded in the highest plant density (500000 plants ha^{-1}) at 120 DAS (Table 4). This finding corroborates with the result of Holahouser and Johshua (2002) who reported a higher plant population resulted in greater leaf area index in soybean. The increase in LAI with increasing population density showed that the increased number of plants per unit area has more than compensated for the decline in leaf area per plant under increasing density.

Table 4:. Leaf area index of pigeon pea at different growth stages as affected by varieties and population densities during 2006 cropping season

Treatment	Leaf area index at different days after sowing								
	30	45	60	75	90	105	120	135	150
Variety									
ICPL 87091	0.04	0.07	0.56	1.17	1.83	3.19a	3.32	1.85b	1.13
ICP 15027	0.03	0.07	0.53	1.13	1.75	2.77b	3.18	2.21a	1.26
LSD$_{0.05}$	NS	NS	NS	NS	NS	0.14	NS	0.24	NS
Population density (plants ha $^{-1}$)									
166666	0.02d	0.05d	0.35d	0.82d	1.31d	2.46d	2.67c	1.90bc	1.01d
200000	0.03cd	0.06c	0.39d	0.94d	1.39cd	2.57d	2.83c	1.84c	1.09cd
250000	0.03c	0.06c	0.47c	1.10c	1.58c	2.81c	2.98c	2.00bc	1.18bc
333333	0.04b	0.08b	0.63b	1.26b	1.97b	3.21b	3.47b	2.13ab	1.30ab
500000	0.06a	0.12a	0.89a	1.64a	2.69a	3.85a	4.32a	2.29a	1.41a
LSD$_{0.05}$	0.01	0.01	0.05	0.14	0.23	0.23	0.32	0.24	0.14
CV%	14.05	8.92	7.08	10.05	10.67	6.40	7.95	9.80	9.69

Means with the same letter in a column in each category are not significantly different at $P < 0.05$, LSD (0.05) = least significant difference at 5% probability level, CV = coefficient of variation, and NS = non-significant difference.

3.3. Effect of planting density on yield and yield components of pigeon pea varieties

Optimum plant density should be maintained to exploit maximum natural resources such as nutrients, sunlight, soil moisture to ensure satisfactory yield (Sharifi*et al.*, 2009). Grain yield per plant was significantly affected by plant density (Table 5). The increase in plant density decreased the seed yield per plant (Table 6). The highest plant density (500000 plants ha^{-1}) decreased the seed yield per plant by 50.96 % compared to the lowest plant density (166666 plants ha^{-1}). The reduction in yield per plant with increasing population density could relate to the decrease in pod number per plant (Biswas*et al.*, 2002). Increasing plant density encourages interplant competition for resources, and consequently, the net photosynthesis would be affected due to less light penetration in the crop canopy as well an increase in the competition for available nutrients that results in poor growth of the plants (Sharifi*et al.*, 2009) and reduction in yield. On the contrary, grain yield per hectare increased with increasing plant density (Table 6). The relationship between grain yield and population density was adequately explained by a linear function (R^2=0.94), which was statistically significant ($P \leq 0.001$) (Fig 2). The highest plant density (500000 plants ha^{-1}) resulted in the maximum yield, increasing the yield by 29.36% compared to the lowest density (166666 plants ha^{-1}).

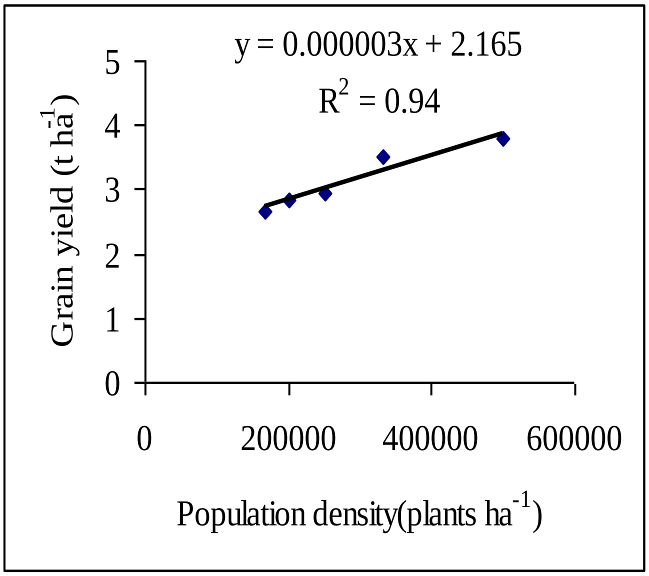

Figure 2: Relationship between population density and grain yield of pigeon pea

This result corroborates the findings of Wallis *et al.* (1981) who reported a population density of 400000-500000 plants ha^{-1} is required to obtain high yields of short duration pigeon pea. The higher yield obtained with high density could be due to the more effective use of resources by the plants. There was no statistically significant difference between the two varieties in grain yield per hectare (Table 6).The number of branches per plant and pod per plant were significantly affected by the effect of varieties and plant density (Table 5). The indeterminate variety (ICP 15027) produced a higher number of branches per plant and pods per plant as compared to determinate variety (ICPL 87091) (Table 6). The mean pod number per plant was 54.6 and 35.3 in ICP 15027 and ICPL 87091, respectively. Due to their genotypic variability in growth habit, the indeterminate variety (ICP 15027) produced a higher number of branches than the determinate variety (ICPL 87091) that could increase the number of pods in the plant. In this study, plant height, branches, and pods per plant seem to function in tandem with one another. This result is in line with the findings of Vijayalakshmi*et al*. (2013) who reported the positive correlation of plant height and branches in pigeon pea

Table 5: Mean square values for yield, yield components, total biomass and harvest index of pigeon pea as affected by population densities and varieties during 2006 cropping season

		Mean squares								
Source	DF	Seed yield plant $^{-1}$ (g)	Seed yield (t ha^{-1})	No of branches plant^{-1}	Pods plant^{-1}	Pods m^{-2}area	Seed pod^{-1}	100 seed wt (g)	Total biomass yield (t ha^{-1})	Harvest index
Replication	2	4.23*	0.17	0.01	306.03	197032.43**	0.01	0.50	0.87	0.00025
V (variety)	1	1.04	0.32	4.49**	2780.18*	1727352.06*	11.16**	74.58*	0.36	0.00082*
Error a	2	0.63	0.04	0.01	98.88	75402.59	0.01	0.81	0.46	0.000024
D (density)	4	54.75***	1.32***	0.21	980.72***	133382.66**	0.0003	0.22	94.06***	0.0078***
V*D	4	1.36	0.11	0.02	96.65	603.56	0.02	0.51	0.25	0.00035
Error b	16	1.11	0.13	0.11	22.47	20056.27	0.02	0.45	0.52	0.00039

* Significant 0.05, ** Significant at 0.01, *** Significant at 0.001 P-levels

An increase in plant density decreased branches per plant and number of pod per plant (Table 6). The highest pod number (60.2) was observed at a plant density of 166666 plants ha^{-1} and the lowest pod number (26.8) at a plant density of 500000 plants ha^{-1}. The decrease in pod number per plant under increasing plant density could be due to the densely planted pigeon pea might have caused mutual shade which may be responsible for the reduction in photosynthetic efficiency and dropping of flowers and pods in lower canopy layers (Biswas*et al*., 2002). Nevertheless, the number of pod per unit area increased as the population density increased.

Plant density did not affect the number of seed per pod and 100-seed weight (Table 6). However, the determinate variety (ICPL 87091) produced a significantly higher number of seeds per pod and 100-seed weight than that of indeterminate variety (ICP 15027) (Table 6). This result is in line with the findings of Kaur and Saini (2018) and Solomon (2002), who did related work on pigeon pea and beans respectively, reported that a determinate variety produced a higher number of seeds per pod than the indeterminate one. In this study, the higher 100-seed weight (10.9 g) was obtained in plants of variety ICPL 87091 compared to variety ICP 15027 (7.7 g) (Table 6). Differences in 100-seed weight of between pigeon pea genotypes were also reported by Kaur and Saini (2018). The variation was due to the differences among genotypes inefficiency in translocations of the photosynthesis to the reproductive part (Chandrakar*et al*., 2015). The grain yield difference between the two varieties was not significant; however, the difference between varieties for yield components (seed number per pod, 100-seed weight, pod per plant, and pod per unit area) was significant (Table 6). The determinate variety (ICPL 87091) had a higher seed number per pod and seed weight than the indeterminate variety (ICP 15027) while more number of pods per plant and per unit area was produced by variety ICP 15027. This compensatory effect resulted in a non-significant variation in grain yield between the two varieties. Table 6 shows that there was no significant variation between the varieties for total biomass. However, the total biomass increased with increasing population density (Table 6). Population density and total biomass showed a linear (R^2=0.99) relationship (Fig 3).

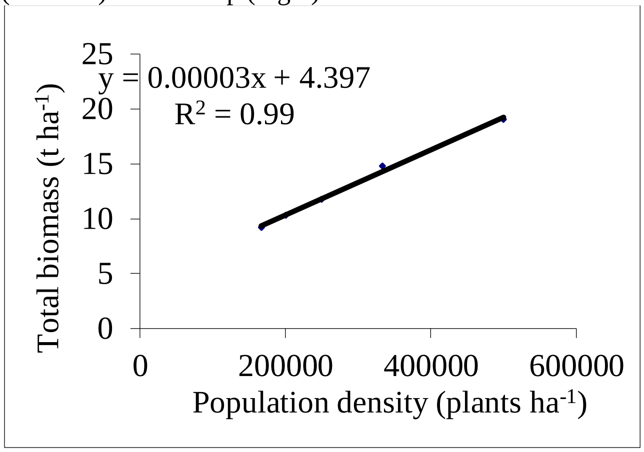

Figure 3: Relationship between population density and total biomass yield of pigeon pea.

The highest biomass (19.00t ha^{-1}) was obtained at the highest population (500000 plants ha^{-1}) and the lowest biomass (9.17 t ha^{-1}) was recorded at the lowest population density (166666 plants ha^{-1}). The increment of biomass with rising population density is due to the increasing number of plants per unit area which was more than compensated for the decrease in biomass produced per plant. In other words, the superiority of growth characters like LAI and dry matter accumulation may be the possible reasons for the production of higher biomass yield (Kaur and Saini, 2018).The ratio of economic yield to biomass is the harvest index. The harvest index of determinate variety (ICPL 87091) was significantly higher than the indeterminate variety (ICP 15027) (Table 6). This finding is in line with the result of Patel *et al*. (2000) who reported that the determinate cultivars had a higher harvest index than the indeterminate ones. The harvest index was reduced with increasing plant density and the maximum harvest index of 0.29 was obtained from the lowest plant density (166666 plants ha^{-1}) (Table 6). The higher harvest index with reduced plant density might be due to higher seed yield per plant at lower plant density. Very high populations in some crops, such as soybean, may decrease harvest index because of lodging or barren plants (Weber *et al*., 1966).

Table 6: The effect of population density and variety on seed yield, yield components, total biomass yield and harvest index of pigeon pea during 2006 cropping season

Treatments	Seed yield (g plant^{-1})	Seed yield (t ha^{-1})	Number of branches plant^{-1}	Number of Pods plant^{-1}	Number of Pods m^{-2}area	Number of Seed pod^{-1}	100-seed weight (g)	Total biomass yield (t ha^{-1})	Harvest index
Variety									
ICPL 87091	11.97	3.26	4.19b	35.31b	929.80b	5.31a	10.86a	13.11	0.26a
ICP 15027	11.59	3.05	4.96a	54.56a	1409.70a	4.09b	7.71b	12.89	0.25b
LSD $_{0.05}$	NS	NS	0.14	15.62	431.42	0.18	1.41	NS	0.01
Population density									
(Plants ha^{-1})									
166666	15.48a	2.67b	4.83a	60.20a	1003.33c	4.72	9.30	9.17e	0.29a
200000	13.60b	2.85b	4.66ab	52.40b	1048.00c	4.70	9.32	10.29d	0.28a
250000	11.76c	2.96b	4.61ab	46.27c	1156.67bc	4.70	9.02	11.76c	0.25b
333333	10.49c	3.50a	4.43ab	38.97d	1298.89ab	4.70	9.23	14.80b	0.24b
500000	7.56d	3.78a	4.36b	26.83e	1341.67a	4.70	9.55	19.00a	0.20c
LSD$_{0.05}$	1.29	0.45	0.41	5.80	173.33	NS	NS	0.88	0.03
CV %	8.96	11.73	7.30	10.55	12.11	2.56	7.21	5.54	7.97

Means with the same letter in a column in each category are not significantly different at $P < 0.05$, LSD (0.05) = least significant difference at 5% probability level, CV = coefficient of variation, and NS = non-significant difference.

3.4. Constraints and opportunities in using planting density

Early pigeon pea varieties require row spacing from 25 to 40 cm (Faroda and Johri., 1981) depending on the availability of resources such as nutrient, sunlight, soil moisture to ensure satisfactory yield (Sharifi*et al*., 2009). The high plant population encourages interplant competition for resources resulting in poor growth of the plants (Sharifi*et al*., 2009). Hence, maintaining the optimum planting density is important not only to maximize the grain yield but also to boost biomass yield for its benefit as feed for poultry, and cows (Saxena*et al*., 2002) and firewood (Yude*et al*., 1993) in many poor and developing countries (Saxena*et al*., 2010). In this study, row spacing of 30 cm and plant spacing of 10 cm (333,333 plants ha^{-1}) is suitable spacing or planting density in the study area for early pigeon pea varieties. This planting density can be applied in other areas with similar agroecology. However, medium and late maturing pigeon pea cultivars are used in Africa (Sakala*et al.*, 2000) even with little production in Ethiopia (Karanja, 2016) that yields low (Mergeai*et al.*, 2001). Hence, researchers, development agents in the sector and policymakers should exert their effort in the popularization of short duration pigeon pea and full implementation of the agronomic package such as the optimum planting density to maximize productivity.

4. Conclusion

The results show that the use of higher planting density increased leaf area index, dry matter yield, total biomass yield and grain yield of pigeon pea and the maximum values for these traits were obtained with the planting density of 500000 plants ha^{-1} though the difference with 333333 plants ha^{-1} was not significant. Because of the absence of significant differences between these planting densities, the planting density of 333333 plants ha^{-1} could be preferred due to the expected ease of management, economy of seed, and lower labor cost. The results indicated no significant difference between varieties for the majority of growth and yield traits. Thus, these varieties could be used interchangeably in the test area. However, it is worthwhile to investigate varied intra-row spacing at wider spatial and temporal scales.

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Conflict of interest

“The authors declare no conflict of interest”.

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