

Growth and productivity of pigeon pea genotypes under different plant geometry and its residual impact on some soil chemical properties.

Abstract

Field experiments were conducted during the 2020 and 2021 cropping seasons at the research fields of CSIR-Savanna Agricultural Research Institute located at Nyankpala in the Guinea savannah agroecology of Ghana. The objective was to test the effect of genotype and plant geometry on the growth and productivity of pigeon pea. The work involved three pigeon pea genotypes (L-2015-2, L-2015-3 and ICP-8863) and four spacing levels; 100 cm x 30 cm, 100 cm x 45 cm, 100 cm x 60 cm and 100 cm x 75 cm. Analysis of variance indicated a significant interaction effect of genotype, year and spacing effect on number of branches per plant, pod length, grain yield, 1000 seed weight and harvest index. Genotype x spacing effect was significant for all traits except the number of seeds per pod. Genotype ICP-8863 at 100 cm x 30 cm produced the tallest plants (294.7 cm) whilst genotype L-2015-3 at 100 cm x 60 cm produced the shortest plants (222.9 cm). Genotype L-2015-2 at 100 cm x 60 cm in 2021 had the highest grain yield (2311 kg/ha) whilst genotype ICP8863 at 100 cm x 60 cm in 2020 had the lowest grain yield (391 kg/ha). A post-2020 cropping season soil analysis revealed improvement in key soil chemical properties, explaining the better crop performance in 2021. Genotype L-2015-2 had the highest overall average grain yield (1484 kg/ha) whilst ICP8863 had the lowest overall grain yield. The study indicated that the different genotypes required different spacing for their optimum yield due to differences in plant architecture, growth and branching habit. Spacing had significant influence on plant height, number of leaves at flowering, number of pods per plant and number of seeds per pod which were significantly and positively correlated with grain yield. Therefore, each genotype should be matched with its preferred spacing for optimum growth and maximum grain yield.

Keywords: Pigeon pea, genotype, plant geometry, productivity, grain yield, soil properties.

Introduction

Pigeon pea is a perennial leguminous food crop which is an excellent source of protein (20-30%), hence it provides opportunities for enhancing household food and nutrition security

(Snapp et al., 2003) It improves soil fertility and benefits cereal crops through nitrogen fixation when they are intercropped or used in crop rotation (Adjei-Nsiah, 2012). It is also used as fodder for domestic animals and enhances ruminant live weight due to its relatively higher nitrogen concentration (Shenkute et al. 2013). It is capable of providing some grain yields for the period of dry spells when other legumes such as field beans have wilted and possibly dried up as a result of its deep rooted and drought-tolerant nature (Sharma et al. 2011). Outlining the importance of pigeon pea, its role cannot be overemphasized as an important component of sustainable cropping systems in Ghana and most especially in the Guinea savanna agro-ecological zone.

Despite its importance in terms of nutrition and soil fertility improvement, the crop has not been promoted to any appreciable extent by the national agricultural research and extension system in Ghana (Adjei-Nsiah, 2012). Pigeon pea is mostly cultivated either as a border crop or on marginal lands for grains, fodder and fuel wood (Marfo 1990). The crop production is limited and constrained and these constraints have resulted in low yields of about 600 to 700 kg/ha instead of potential yield of 2000-3000kg/ha. The constraints include agronomic, biotic and abiotic factors. However, long maturing periods of landrace, lack of improved varieties and drought are the most important limiting factors in pigeon pea production in Northern Ghana. For instance, available landraces mature in over 10 months which is longer than the average rainy months (3 – 5 months) in the Sudan and the Guinea Savannah zones of Northern Ghana and hence faces long term drought which contribute to low yields. In addition, the crop faces the risk of bush fire and destruction of the fields by stray animals during the long dry spell which directly or indirectly discourages farmers from investing in pigeon as a commercial crop.

Currently, the pigeon pea breeding program at CSIR-Savanna Agricultural Research Institute (SARI) have developed and identified some promising pigeon pea genotypes that are suitable for cultivation in the Sudan and the Guinea Savannah zones of Northern Ghana. These promising genotypes in a preliminary and advanced trial outperformed the landraces in terms of grain yield and maturity period. However, genotypes are different in their yield potential depending on many complex physiological processes taking place in different parts of the plant, which are controlled by both genetic makeup of plant and the environment (Tigga et al., 2017). Maximum yield in a particular cultivar and environment can be obtained at the density where competition between the plants is low. This will be attained at an optimum plant density, which do not only

utilize light, moisture and nutrients more efficiently but also avoids excessive competition among the plants. Amoako et al. (2020) and (Ndiaga, (2001) also stated that newly developed crop varieties possess different growth habits and phenotypic attributes that needs to be subjected to different plant spacing and population densities to express their full seed yield potential. Hence development and identification of an appropriate and specific plant spacing for the newly developed genotypes and recommending them to farmers can be one of the ways to increase the yield potential of pigeon pea in Ghana. Therefore, this study was carried out to determine the growth and yield performance of pigeon pea genotypes under different plant geometry and its residual effect on some soil chemical properties.

Materials and Methods

The experiment was conducted in 2020 and 2021 cropping seasons at the CSIR-Savanna Agricultural Research Institute located at Nyankpala (9°25'N, 0°58'W) in the Northern Region of Ghana. The Guinea Savannah zone covers over 40% of the entire land area of Ghana and is characterised by high temperatures and low humidity for most parts of the year (EPA, 2003). The climate is a warm, semiarid with mono-modal annual rainfall of 1200 mm between May/June and October. The area also experiences a long windy dry season (harmattan) annually from November to April. Intermittent dry spells, often lasting up to two weeks also occur during the rainy season (Alua et al., 2018). The land has a gentle slope of about 2 %. The soil is well-drained Voltaian sandstone, locally known as the Tingoli series and classified as Ferric Luvisol (FAO-UNESCO, 1977).

Experimental design and treatments

The experimental design was a randomized completed block design with three replications in 3 × 4 factorial arrangements: three pigeon pea genotypes levels (L-2015-2, L-2015-3 and ICP-8863) and four spacing levels (100 cm x 30 cm, 100 cm x 45 cm, 100 cm x 60 cm and 100 cm x 75 cm). Each plot measured 40 m long and 4 m wide.

Land preparation, planting and field management

The experiment was conducted under rain fed conditions. The field was ploughed and harrowed, after which ridges were made. Planting was done in June in both 2020 and 2021 cropping season. A pre-emergence herbicide (Pendimethalin) was applied at 2.5 litres ha⁻¹ immediately after planting. Two seeds were sown and thinned after emergence to maintain one plant per stand. At two weeks after planting, phosphorus was applied as triple super phosphate (TSP) at the rate of 50 kg P₂O₅ ha⁻¹ to all the plots. Hand weeding was done at 5 and 10 weeks after sowing.

Data collection and Analysis

Soil samples were taken from each plot, bulked and mixed thoroughly to obtain a composite sample. A subsample of 200 g was taken and analysed for soil texture, pH in water using soil to water ratio of 1:2.5 (Page et al., 1982). Total nitrogen of soil from the experimental plot was determined by Kjeldahl distillation and titration method (Bremner and Keeney, 1965). Available phosphorus was measured using Bray and Kurtz method (Bray and Kurtz, 1945). Exchangeable potassium was determined using flame photometry PFP7 after extraction with ammonia acetate. Organic carbon was determined by the wet digestion method (Nelson and Sommers, 1982) before planting was done. Plant height was measured before harvesting using a meter rule from the base of the plant to the tip of the main stem for each of the five randomly selected tagged plants and average calculated for each plot. Similarly, number of branches and number of leaves were taken from these five tagged plants and an average value was calculated. Leaf area index (LAI) was measured at full bloom stage using AccuPAR model LP-80 PAR/LAI Ceptometer (Decagon Devices, Pullman WA, USA). Number of pods per plant was determined by counting pods of five randomly selected plants at harvest. Five pods were collected at random from the five selected plants and their length was measured in cm and the mean was calculated and expressed as the length of pod. Number of seeds per pod was counted from five randomly selected pods at harvest. A random sample from the yield of two inner rows was taken out and hundred seeds were counted and weighed. The grain yield obtained from the two inner rows was sun dried to a moisture content of 10% using a moisture meter. These were weighed and each weight was converted to kilogram per hectare. After harvesting, plants from the two inner rows were allowed to dry in the sun to a moisture content of 10%, then weighed and converted to

kilogram per hectare to determine the biomass for each plot. Harvest index (HI) was computed as the ratio of economic yield (kg ha^{-1}) to the total biological yield (kg ha^{-1}) $\times 100$. Where, economic yield is the grain yield and the total biological yield is the summation of the total biomass and grain yield plus pod chaff. Data collected was subjected to analysis of variance using GenStat software 12th edition (Payne et al., 2009) and the least significant difference at 5% probability was used for mean separation.

Results

Weather conditions during the period of the experiment

Total rainfall recorded over the experimental period (May–December) was generally higher in 2020 compared with 2021. The highest amount of rainfall was recorded in July 2020 whereas in 2021 the highest amount of rainfall was recorded in August. Average monthly temperature (May–December) was 28.3 °C and 28.2 °C in 2020 and 2021 cropping, respectively. Average relative humidity (May–December) was higher in 2020 compared to 2021 cropping season (Figures 1 and 2).

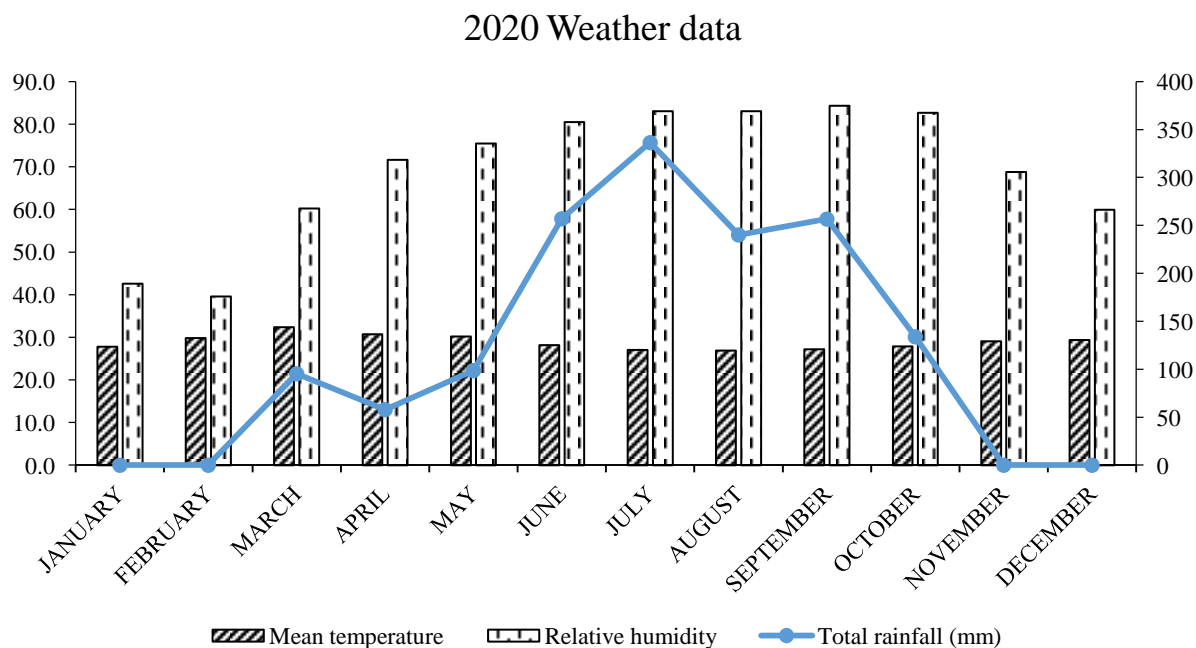


Figure 1. Monthly mean temperature, relative humidity and rainfall for the 2020 cropping season

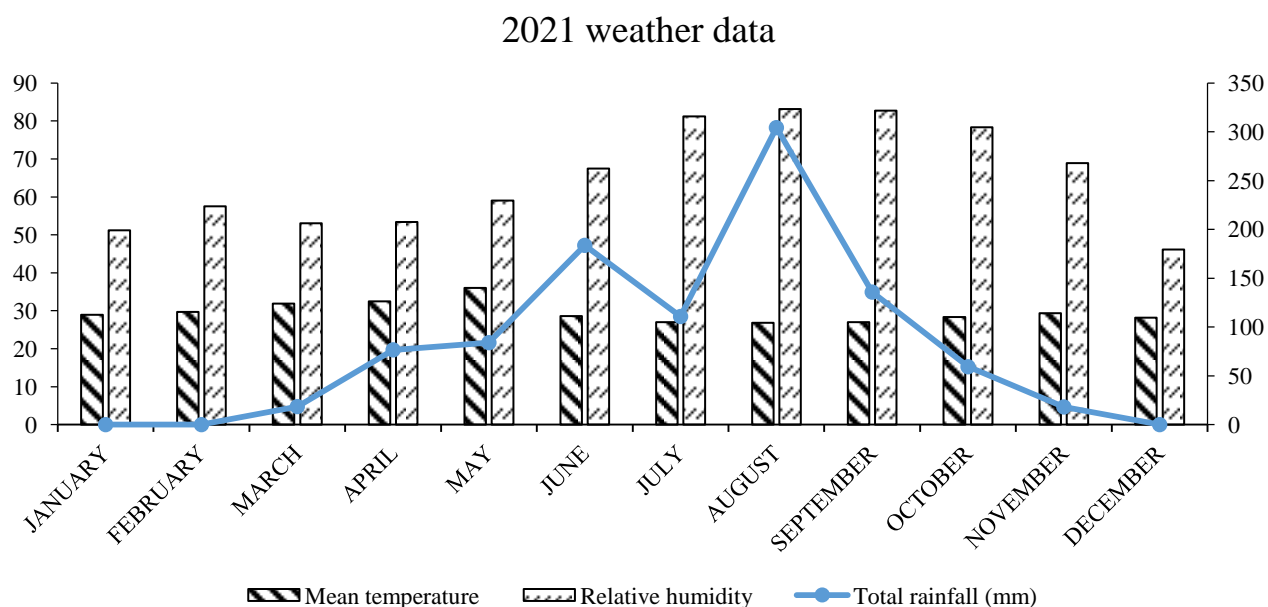


Figure 2. Monthly mean temperature, relative humidity and rainfall for the 2021 cropping season

Baseline soil Analysis

Table 1. shows the baseline soil analysis for 2020 and 2021 cropping season. Soil chemical properties such as pH, total nitrogen, available phosphorus, exchangeable potassium and organic Carbon were higher in 2021 than in 2020.

Year	pH	Organic carbon (%)	Total nitrogen (%)	Available P (mg/kg)	Potassium (mg/kg)	Texture		
						% Sand	% Silt	% Clay
2020	4.76	0.643	0.058	5.614	49	70.56	28.92	0.52
2021	5.80	1.209	0.093	17.311	62	70.56	28.92	0.52

Table 1. Physical and chemical properties of soil in the experimental site

Crop Performance

Number of leaves per plant at flowering

Interaction effect of genotype and spacing, the genotype and spacing main effect on the number of leaves per plant differed significantly in both 2020 and 2021 cropping season (Table 2). Number of leaves was significantly highest with genotype L-2015-3 at 100 cm x 60 cm

compared with the other treatment combinations in 2020 cropping season. On the contrary, genotype L-2015-2 100 cm x 60 cm produced significantly the most leaves at flowering in 2021 cropping season. However, it was significantly similar to genotypes L-2015-2 at 100 cm x 75 cm, L-2015-3 at 100 cm x 60 cm and L-2015-3 at 100 cm x 60 cm. Genotype ICP -8863 at 100 cm x 60cm had significantly fewer leaves in 2020 cropping season whereas in 2021 cropping, ICP -8863 at 100 cm x 60cm and ICP -8863 at 100 cm x 30 cm had the lowest number of leaves at flowering.

Number of Branches per plant at flowering

Interaction effect of genotype and spacing, the genotype and spacing main effect on the number of branches per plant differed significantly in both 2020 and 2021 cropping season (Table 2). Number of branches at flowering was significantly highest for genotype L-2015-2 at 100 cm x 60 cm compared with the other treatment combinations in both 2020 and 2021 cropping season. However, it was significantly similar to genotypes L-2015-3 at 100 cm x 75 cm in 2021 cropping season. Genotype L-2015-3 at 100 cm x 45 cm had significantly fewer branches at flowering in 2020 cropping season. Whereas in 2021 cropping, ICP -8863 at 100 cm x 30 cm had fewer branches at flowering.

Plant Height at physiological maturity

Interaction effect of genotype and spacing as well as spacing main effect on plant height at physiological maturity did not differ significantly in 2020 cropping season. However, genotype main effect had significant effect on plant height. In 2021 cropping season, interaction effect of genotype and spacing as well as genotype main effect on plant height at physiological maturity differed significantly. However, there was no significant effect of spacing main effect on plant height at physiological maturity in 2021 cropping season (Table 2). The tallest plants were produced by genotype ICP -8863 and it was significantly different from genotypes L-2015-2 60 cm and L-2015-3, with genotype L-2015 producing the shortest plants in 2020 cropping season. Genotype ICP -8863 at 100 cm x 30 cm obtained taller plants compared with the other treatment

combinations whilst the shortest plants were recorded by L-2015-3 at 100 cm x 60 cm and L-2015-3 at 100 cm x 30 cm in 2021 cropping season.

Leaf area index (LAI) at flowering

Interaction effect of genotype and spacing, the genotype and spacing main effect on leaf area index at flowering differed significantly in both 2020 and 2021 cropping season (Table 2). Genotype L-2015-3 at 100 cm x 60 had significantly the highest leaf area index in both 2020 and 2021 cropping season. However, in 2020 cropping season, it was statistically similar to those obtained by genotype L-2015 2 at 100 cm x 75 cm. In both 2020 and 2021 cropping season, genotype ICP 8863 at 100 cm x 45 cm obtained the lowest leaf area index.

Table 2. Effect of genotype and spacing on some growth parameters of pigeon pea in 2020 and 2021 cropping season.

Treatments	Number of leaves at flowering		Number of branches at flowering		Plant height at physiological maturity		LAI at flowering	
	2020	2021	2020	2021	2020	2021	2020	2021
Genotypes								
L-2015-2	914.9	1138.0	44.2	49.5	236.2	267.7	1.61	1.78
L-2015-3	912.2	1117.0	43.3	46.8	216.2	290.4	1.20	1.52
ICP-8863	676.6	894.5	40.9	44.0	253.2	305.9	0.88	0.85
LSD (p<0.05)	42.18	42.69	1.79	2.02	15.26	13.83	0.19	0.22
Spacing								
100 cm x 30 cm	809.4	1004.6	39.3	43.2	242.8	289.6	0.94	1.06
100 cm x 45 cm	775.0	1011.2	40.9	43.7	239.2	291.5	1.11	1.27
100 cm x 60 cm	886.9	1095.7	46.3	50.2	224.8	288.0	1.45	1.80
100 cm x 75 cm	866.9	1087.9	44.7	50.1	234.0	282.8	1.29	1.40
LSD (p<0.05)	48.70	49.30	2.07	2.22	17.63	15.97	0.22	0.26
Interaction								
(L-2015-2) x (100 cm x 30 cm)	881.8	1014.9	40.8	43.0	245.2	291.1	1.00	1.25
(L-2015-2) x (100 cm x 45 cm)	744.6	1065.6	39.1	45.1	227.3	277.7	1.53	1.76
(L-2015-2) x (100 cm x 60 cm)	1025.6	1242.5	50.5	53.8	239.1	301.5	2.07	2.58
(L-2015-2) x (100 cm x 75 cm)	1007.4	1229.1	46.5	53.1	233.1	291.2	1.85	1.51
(L-2015-3) x (100 cm x 30 cm)	831.2	1118.5	36.9	44.6	215.9	255.7	0.96	1.11
(L-2015-3) x (100 cm x 45 cm)	721.4	1065.9	43.9	42.9	232.0	297.7	1.02	1.31
(L-2015-3) x (100 cm x 60 cm)	1140.0	1164.5	48.1	49.7	187.6	258.3	1.30	1.97
(L-2015-3) x (100 cm x 75 cm)	956.2	1119.2	44.4	50.3	229.4	259.0	1.10	1.69
(ICP-8863) x (100 cm x 30)	715.2	880.3	40.2	41.9	267.3	322.0	0.85	0.83
(ICP-8863) x (100 cm x 45)	859.0	902.3	39.6	34.0	258.4	299.0	0.77	0.73

(ICP-8863) x (100 cm x 60)	495.0	880.0	40.3	44.1	247.7	304.3	0.97	0.84
(ICP-8863) x (100 cm x 75)	637.2	915.5	43.3	47.1	239.6	298.1	0.92	1.01
LSD (p<0.05)	84.36	85.39	1.73	4.03	30.53	27.6	0.38	0.45
Mean	834.6	1049.9	42.80	46.8	235.2	288.0	1.20	1.38
CV (%)	6.0	4.8	4.2	5.1	7.7	5.7	18.7	19.0

LAI = Leaf area index

Number of pods per plant

Interaction effect of genotype and spacing, the genotype and spacing main effect on the number of branches per plant differed significantly in both 2020 and 2021 cropping season (Table 3). Genotype L-2015-2 at 100 cm x 60 produced significantly more pods per plant in 2020 cropping season though it was significantly similar to genotype L-2015-2 at 100 cm x 75 cm. Similarly, in 2021 cropping season, genotype L-2015-2 at 100 cm x 60 had the highest number of pods per plant. However, it did not differ significantly from genotypes L-2015-2 at 100 cm x 75 cm and L-2015-3 at 100 cm x 60cm. In both 2020 and 2021 cropping season, genotype ICP -8863 at 100 cm x 30 cm produced few pods per plant but it was statistically similar to genotype ICP -8863 at 100 cm x 45 cm.

Pod Length per plant (cm)

Interaction effect of genotype and spacing, the genotype and spacing main effect on number of branches per plant differed significantly in both 2020 and 2021 cropping season (Table 3). Genotype L-2015-2 at 100 cm x 60 had significantly longer pods per plant in 2020 but it was significantly similar to genotypes L-2015-3 at 100 cm x 75 cm and L-2015-2 100 cm x 30 cm. A similar observation was made in 2021 cropping season, with genotype L-2015-2 at 100 cm x 60 producing longer pods than the other treatment combinations. However, it did not differ significantly with genotype L-2015-3 at 100 cm x 75 cm. In both 2020 and 2021 cropping season, genotype ICP -8863 at 100 cm x 45 cm produced significantly the shortest pods but it was statistically similar to all the other treatment combinations apart from genotypes L-2015-2 at 100 cm x 60 cm, L-2015-3 at 100 cm x 75 cm and L-2015-2 at 100 cm x 75 cm.

Number of seeds per pods

Interaction effect of genotype and spacing, the genotype and spacing main effect on the number of seeds per pod differed significantly in both 2020 and 2021 cropping season (Table 3). Genotype L-2015-2 at 100 cm x 60 cm produced significantly more seeds per pod in 2020 cropping season. However, it was significantly similar to genotype L-2015-2 at 100 cm x 75 cm. In a similar manner, genotype L-2015-2 at 100 cm x 60 had significantly the highest number of seeds per pod in 2021 cropping season. In 2020 cropping season, genotype L-2015-2 at 100 cm x 30 cm produced few seeds per pod but it was statistically similar to all the other treatment combinations except for genotypes L-2015-2 at 100 cm x 60cm, L-2015-2 at 100 cm x 75 cm and L-2015-3 at 100 cm x 75 cm. In 2021 cropping season, the lowest number of seeds were produced by genotype L-2015-3 at 100 cm x 45 cm. However, it did not differ significantly from all the other treatment combinations apart from genotypes L-2015-2 at 100 cm x 60, L-2015-3 at 100 cm x 60 cm and L-2015-2 at 100 cm x 75.

Grain yield per plant (g)

Interaction effect of genotype and spacing as well as genotype main effect on grain yield per plant differed significantly in 2020 cropping season. However, spacing main effect had no significant effect on grain yield per plant. In 2021, interaction effect of genotype and spacing, the genotype and spacing main effect on grain yield per plant differed significantly (Table 3). In both 2020 and 2021, genotype L-2015-2 at 100 cm x 60 had significantly the highest grain yield per plant and it was followed by genotypes L-2015-3 at 100 cm x 60 cm and L-2015-3 at 100 cm x 75 cm in 2020 and 2021, respectively. Genotype ICP -8863 at 100 cm x 60cm had significantly the lowest grain yield per plant in 2020 but in 2021, genotype ICP -8863 at 100 cm x 45 cm had the lowest grain yield per plant.

Table 3. Effect of genotype and spacing on some yield components of pigeon pea in 2020 and 2021 cropping season.

Treatments	Number of pods	Pod Length	Number of	Grain yield per
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	per plant		(cm)		seeds per pod		plant (g)	
	2020	2021	2020	2021	2020	2021	2020	2021
Genotypes								
L-2015-2	1542	1583	4.8	4.7	3.7	3.8	158.3	171.6
L-2015-3	1433	1486	4.7	4.4	3.5	3.5	151.6	145.3
ICP-8863	1218	1152	4.0	3.9	3.5	3.4	135.1	110.6
LSD (p<0.05)	82.1	99.7	0.12	0.41	0.20	0.22	15.52	27.47
Spacing								
100 cm x 30 cm	1177	1102	4.6	3.9	3.2	3.4	143.4	105.8
100 cm x 45 cm	1185	1159	4.3	3.9	3.4	3.4	143.8	110.0
100 cm x 60 cm	1577	1725	4.7	4.8	3.7	3.9	157.5	185.9
100 cm x 75 cm	1652	1643	4.3	4.7	3.7	3.6	148.5	168.3
LSD (p<0.05)	94.8	115.1	0.14	0.47	0.23	0.25	17.92	31.72
Interaction								
(L-2015-2) x (100 cm x 30 cm)	1265	1232	4.8	4.0	3.2	3.4	149.5	113.4
(L-2015-2) x (100 cm x 45 cm)	1258	1184	4.8	4.0	3.4	3.5	132.7	120.3
(L-2015-2) x (100 cm x 60 cm)	1869	2006	5.0	5.9	4.2	4.4	193.1	284.7
(L-2015-2) x (100 cm x 75 cm)	1774	1908	4.7	4.7	3.9	3.8	157.7	168.0
(L-2015-3) x (100 cm x 30 cm)	1328	1221	4.7	3.9	3.3	3.5	142.4	118.9
(L-2015-3) x (100 cm x 45 cm)	1227	1241	4.5	3.9	3.4	3.2	158.4	126.5
(L-2015-3) x (100 cm x 60 cm)	1507	1817	4.8	4.4	3.5	3.9	161.2	156.7
(L-2015-3) x (100 cm x 75 cm)	1671	1667	4.2	5.3	3.8	3.5	144.3	179.1
(ICP-8863) x (100 cm x 30)	937	853	4.2	3.9	3.4	3.4	138.2	85.2
(ICP-8863) x (100 cm x 45)	1069	1051	3.7	3.8	3.4	3.3	140.3	83.1
(ICP-8863) x (100 cm x 60)	1355	1352	4.2	3.9	3.5	3.3	118.1	116.3
(ICP-8863) x (100 cm x 75)	1513	1354	4.0	4.0	3.5	3.5	143.6	157.8
LSD (p<0.05)	164.2	199.4	0.23	0.279	0.39	0.44	31.04	54.95
Mean	1398	1407	4.8	4.4	3.5	3.6	148.3	142.5
CV (%)	6.9	8.4	3.1	11.2	6.5	7.2	12.4	22.8

Grain yield (kg ha⁻¹)

Interaction effect of genotype and spacing, the genotype and spacing main effect on grain yield per hectare differed significantly in 2020 cropping season. In 2021, Interaction effect of genotype and spacing as well as genotype main effect on grain yield per hectare differed significantly. However, spacing main effect had no significant effect on grain yield per hectare (Table 4). Significantly, genotype L-2015-2 at 100 cm x 60 had the highest grain yield in both 2020 and 2021 cropping season. However, in 2020 cropping season, it was significantly similar to genotypes L-2015-3 at 100 cm x 60 cm, L-2015-2 at 100 cm x 75 cm, L-2015-2 at 100 cm x

45 cm, ICP 8863 at 100 cm x 30 cm and L-2015-2 at 100 cm x 30 cm. Significantly, genotype ICP -8863 at 100 cm x 60cm had the lowest grain yield in both 2020 and 2021 cropping season.

Biomass yield (kg ha⁻¹)

Interaction effect of genotype and spacing, the genotype and spacing main effect on biomass yield per hectare differed significantly in 2020 cropping season. However, in 2021 cropping season, only the genotype main effect had significant influence on biomass yield per hectare (Table 4). Genotype ICP -8863 at 100 cm x 30 cm x 60 had significantly the highest biomass yield per hectare in 2020 cropping season. However, it was significantly similar to those obtained by genotypes ICP -8863 at 100 cm x 45 cm and L-2015-2 at 100 cm x 30 cm. In 2021 cropping season, genotype L-2015-2 obtained the highest biomass yield per hectare but it was statistically similar to genotype ICP 8863. Genotype ICP -8863 at 100 cm x 75 cm obtained the lowest biomass yield per hectare in 2020 cropping season. The lowest biomass yield per hectare was obtained by genotype L-2015-3 in 2021 cropping season

Thousand seed weight, (g)

Interaction effect of genotype and spacing, the genotype and spacing main effect on thousand seed weight differed significantly in both 2020 and 2021 cropping season (Table 4). Significantly, genotype L-2015-2 at 100 cm x 60 had the highest thousand seed weight compared to the other treatment combinations in both 2020 and 2021 cropping season. Genotype L-2015-3 at 100 cm x 30 cm had significantly the lowest thousand seed weight in 2020 cropping season whereas in 2021, L-2015-3 at 100 cm x 30 cm had the significantly the lowest thousand seed weight.

Harvest index

Interaction effect of genotype and spacing, the genotype and spacing main effect on harvest index differed significantly in 2020 cropping season. In 2021 cropping season, interaction effect of genotype and spacing as well as genotype main effect on harvest index differed significantly.

However, there was no significant effect of spacing main effect on harvest index in 2021 (Table 4). Significantly, genotype ICP -8863 at 100 cm x 75 cm had the highest harvest index in 2020 but it did not differ significantly with genotype L-2015-3 at 100 cm x 75 cm. However, in 2021 cropping season, genotype L-2015-2 at 100 cm x 60 cm had significantly the highest harvest index which was statistically similar to genotype L-2015-3 at 100 cm x 30 cm. Genotype ICP -8863 at 100 cm x 45 cm obtained significantly the lowest harvest index in both 2020 and 2021 cropping.

Table 4. Effect of genotype and spacing on some yield components of pigeon pea in 2020 and 2021 cropping season.

Treatments	Thousand seed weight, g		Grain yield, kg/ha		Biomass yield, kg/ha		Harvest index, %	
	2020	2021	2020	2021	2020	2021	2020	2021
Genotypes								
L-2015-2	78.7	85.9	1103	1866	7167	11183	13.46	15.07
L-2015-3	70.6	80.7	945	1363	5994	8833	13.99	13.50
ICP-8863	68.3	72.0	666	1311	6559.	10050	10.30	11.83
LSD (p<0.05)	2.32	4.06	63.9	132.2	558.3	1713.8	1.02	2.487
Spacing								
100 cm x 30 cm	65.8	70.2	980	1572	7755	10089	11.39	14.11
100 cm x 45 cm	69.1	73.9	808	1428	7445	10156	10.14	12.46
100 cm x 60 cm	78.1	69.9	902	1595	6501	9744	11.68	14.51
100 cm x 75 cm	77.9	89.8	927	1460	4591	10100	17.14	12.78
LSD (p<0.05)	2.68	4.69	72.6	152.6	644.6	1979.0	1.18	2.872
Interaction								
(L-2015-2) x (100 cm x 30 cm)	65.1	72.9	1048	1689	8331	13400	11.17	11.39
(L-2015-2) x (100 cm x 45 cm)	70.0	76.3	1059	1529	7000.	10667	13.14	12.55
(L-2015-2) x (100 cm x 60 cm)	96.5	102.8	1166	2311	7001	9333	14.30	21.33
(L-2015-2) x (100 cm x 75 cm)	83.1	91.7	1139	1935	6334	11333	15.24	14.99
(L-2015-3) x (100 cm x 30 cm)	63.3	66.9	833	1589	5935	8033	12.46	16.79
(L-2015-3) x (100 cm x 45 cm)	64.7	75.4	834	1373	6500	8467	11.57	13.92
(L-2015-3) x (100 cm x 60 cm)	71.3	86.3	1150	1257	7168	9933	13.90	11.21
(L-2015-3) x (100 cm x 75 cm)	83.3	94.1	961	1225	4373	8900	18.04	12.10
(ICP-8863) x (100 cm x 30)	69.1	70.8	1058	1428	9000	8833	10.54	14.15
ICP-8863) x (100 cm x 45)	72.3	69.3	533	1381	8834	11333	5.69	10.90
ICP-8863) x (100 cm x 60)	66.4	63.7	391	1217	5334	9967	6.84	10.99
ICP-8863) x (100 cm x 75)	67.2	83.5	683	1220	3067	10067	18.14	11.27
LSD (p<0.05)	4.64	8.12	125.8	264.3	1116.5	3427.7	2.04	4.97
Mean	72.7	79.5	904	1514	6573	10022	12.59	13.47
CV (%)	3.8	6.0	8.2	10.3	10.0	20.2	9.6	21.8

Pearson correlation among traits

Pearson correlation analysis indicated that grain yield was significantly ($P < 0.001$) and positively correlated with all the traits apart from number of branches at harvest (Table 5). The strongest correlations with grain yield were in the order number of leaves at flowering ($r = 0.57^{***}$), harvest index ($r = 0.51^{***}$), plant height at harvest ($r = 0.49^{***}$), leaf area index ($r = 0.48^{***}$), number of seeds per pod ($r = 0.27^*$), pod length ($r = 0.26^*$) and number of pods per plant ($r = 0.26^*$). Though the correlation between grain yield and number of branches at harvest was not significant, number of branches at harvest positively correlated with a number of other traits such as 1000 seed weight ($r = 0.53^{***}$), number of pods per plant ($r = 0.53^{***}$), LAI ($r = 0.51^{***}$), pod length ($r = 0.49^{***}$), number of seeds per pod ($r = 0.37^{**}$), HI ($r = 0.31^{**}$) and number of leaves at flowering ($r = 0.31^{**}$). All these traits were positively correlated with grain yield.

Table 5. Pearson correlation analysis showing the interrelationship between grain yield and other traits of three pigeon pea genotypes subjected to four spacing levels

Grain_yld(kg/ha)	1	-											
Plt ht@harvest	2	0.49***	-										
No. levs@flwer	3	0.74***	0.18 ns	-									
No. bran@harvest	4	0.11ns	-0.38***	0.31**	-								
No. pods/plant	5	0.26*	-0.17 ns	0.47***	0.53***	-							
Pod lent	6	0.26*	-0.28**	0.33**	0.49***	0.61***	-						
No. seeds/pod	7	0.27*	0.15 ns	0.23 ns	0.37**	0.42***	0.34	-					
LAI	8	0.48***	0.01 ns	0.57***	0.51***	0.68***	0.56	0.48***	-				
HI	9	0.51***	-0.05 ns	0.37***	0.31**	0.44***	0.34	0.14 ns	0.39***	-			
1000SWT (g)	10	0.50***	0.16 ns	0.64***	0.53***	0.68***	0.49	0.52***	0.73***	0.36**	-		
Biom yld (kg/ha)	11	0.57***	0.59***	0.43***	-0.20 ns	-0.17 ns	-0.15	0.10 ns	0.08 ns	-0.38**	0.18 ns	-	
		1	2	3	4	5	6	7	8	9	10	11	

Grain_yld (kg/ha) = Grain yield (kg/ha), Plt ht@harvest = plant height at harvest (cm), No. levs@flwer = Number of leaves at flowering, No. bran@harvest = Number of branches at harvest, No. pods/plant = number of pods per plant, Pod lent = Pod length (cm), No. seeds/pod = Number of seeds per pod, LAI = Leaf area index, HI = Harvest index, 1000SWT (g) = 1000 seed weight (g), Biom yld (kg/ha) = Biomass yield (kg/ha)

Discussion

In general, growth and yield parameters were significantly affected by the interaction of genotype and spacing. The significant variety and spacing interactive effect confirm different spacing preferences by different varieties. Genotype L-2015-2 at a wider spacing of 100 cm x 60 cm had significantly the highest grain yield in both cropping seasons. One might have expected the narrow spacing of 100 cm x 30 cm to have resulted in low grain yields. However, that was not the case, rather genotype ICP -8863 at a wider spacing of 100 cm x 60 cm had significantly the lowest grain yield. Thus the results of this experiment confirm the assertions of Kumar et al. (2016) who indicated that each genotype has its own requirements of spacing and nutrients for proper growth and therefore new genotypes need to be subjected to different spatial arrangements to determine the appropriate population density for maximum growth and development in a particular season. Grain yield of genotype ICP -8863 at a narrow spacing of 100 cm x 30 cm was significantly similar to grain yield of genotype L-2015-2 at a wider spacing of 100 cm x 60 cm. This result is in agreement with the findings of Deng et al. (2012) who reported that there is an intermediate seeding density for an annual crop that maximizes yield at harvest. As intra row spacing increases from 60 cm to 75 cm, yield reduction of 2.4 % and 19.4 % were observed for genotype L-2015-2 in 2020 and 2021 cropping seasons respectively. This might be due to the fact that, when seeds are planted at lower density, yields are reduced because the plants grow to mature size without using all available resources and as such beyond a certain limit yield cannot be increased with increasing intra row spacing (Amoako et al., 2020).

Higher grain yield with genotype L-2015-2 at 100 cm x 60 cm could be attributed to the significant increase in the number of pods per plant, number of seeds per pod, grain yield per plant and thousand seed weight. Genotype L-2015-2 produced more pods per plant at a wider spacing of 100 cm x 60 cm. This results further corroborate findings of Ayo-Vaughan et al. (2011) who also indicated that yield is a function of population density, number of pods per plant, the number of seeds per pod and the individual seed weight. Higher number of pods per plant could be attributed to significantly higher number of branches obtained by genotype L-2015-2 at 100 cm x 60 cm. The result of this experiment confirms the findings of several authors (Tigga et al., 2017), Bakry et al. (2011), Abubaker (2008) and Chandhla (2005) who reported that wider row spacing gave significantly higher number of pods compared to narrow row

spacing in pigeon pea and common bean and they explained that lower populations are more efficient in utilizing the resources of production than the higher plant densities. However, from our experiment, number of pods per plant was much lower when spacing was increased from 60 cm to 75 cm. In a similar study, Tigga et al. (2017) observed higher number of branches under the wider spacing and attributed this to better growth of plant because of optimum growth resources available to individual plant and their maximum utilization throughout the growth periods as per requirement of the crop. Number of seeds per pod increased with increasing intra row spacing for most of the genotypes evaluated. However, as intra row spacing increases above 60 cm, there was a decrease in the number of seeds per pod. This result is an indication that optimum intra-row spacing which avoids excessive competition and at the same time utilizes soil moisture and nutrient more effectively can result in higher number of seeds per pod.

Grain yield per plant for genotype L-2015-2 increased by 29.2% and 151.1% in 2020 and 2021 respectively, when intra row spacing was increased from 30 to 60 cm. The increased in grain yield per plant at an intra-row spacing of 60 cm might have compensated for higher grain yield per hectare even though there was a reduction in plant population at this spacing compared to the narrow spacing. The results of this experiment is in line with the findings of Nandan and Kumar (2005) who indicated that optimum plant population is a pre-requisite for obtaining high yields. Leaf area index (LAI) which is defined as the one-sided green leaf area per unit ground surface area is an important source in manufacturing photo assimilates for determining dry matter accumulation and crop yield (Nagaraj et al, 2019). Hence higher grain yield achieved by genotype L-2015-2 at 100 cm x 60 could also be as a result of the higher LAI it obtained. An increase in LAI results in better utilization of solar energy, thus leading to higher dry matter accumulation through the process of photosynthesis (Nagaraj et al, 2019). The higher LAI obtained by L-2015-2 at 100 cm x 60 might also be due to less competition and reduced shading among plants produced on the wider intra-row spacing thereby increasing light penetration through plant canopy at lower population density (Amoako et al., 2020). However, as the intra-row spacing increased from 60 cm to 75 cm, LAI reduced. Harvest index which is the ability of a plant to convert the dry matter into economic yield was highest with genotype ICP -8863 at 100 cm x 75 cm in 2020. On the contrary, in 2021, genotype L-2015-2 at 100 cm x 60 had the highest harvest index. Although biomass yield was highest with genotype ICP -8863 100 cm x 30 cm, biomass production might have compromised grain yield and also due to higher accumulation of

dry matter in the shoot of plants at the higher population density (Amoako et al., 2020). Spacing had significant influence on a number of traits that were positively correlated with grain yield. Some of these include number of leaves at flowering, leaf area index, number of pods per plant, etc. This suggests that careful selection of genotype and spacing should be done so that these yield dependent traits would not be negatively affected in that particular genotype.

Pigeon pea's effect on some soil chemical properties in the second year

The results for some chemical properties of the soil as at the start of the second cropping season indicated general improvement in all the soil chemical parameters determined. These improvements explain the better growth and yield performance of pigeon pea in the 2021 cropping season.

Soil pH

The soil pH increased by 1.04 units. This increment was however higher than that observed by Tadesse and Abebe (2019), who recorded an increment in soil pH from 5.06 to 5.3 as compared to values obtained in the previous two years. Musokwa and Mafongoya, (2021) also found soil pH to increase by 0.42 units after a two-year pigeon pea fallow period. The increase in soil pH could be attributed to the complete decomposition of the plant residues (because of its low C/N ratio) consequently, limiting the formation of weak organic acids (caused by intermediate decomposition) which might have favored acidity, hence leading to increased soil pH.

Soil organic carbon

The soil organic carbon content doubled at the end of the first season. Similar result was observed by Elema et al. (2022), Tadesse and Abebe (2019) and Egbe and Bar-Anyam (2010). Elema et al. (2022) reported that, pigeon pea can add about 1.11% OC and plays a crucial role in soil organic matter restoration. The high amounts of leaf litters (coming from a high shoot biomass) of up to about 2 t ha⁻¹ Adjei-Nsiah, (2012) in one season could be considered a potential source of the carbon. In the transitional zone of Ghana for instance, Adjei-Nsiah,

(2012) found a pigeon pea shoot biomass yield of about 25.5 tons within 16 months, which can easily mineralize to release organic carbon.

Soil nitrogen

An increase in soil N (0.058 % to 0.093 %) was in agreement with a lot of similar work done. Elema et al. (2022), Adjei-Nsiah, (2012), Egbe and Kalu (2006) and Egbe and Adeyemo (2006) have all observed similar increments. The ability for pigeon pea to fix atmospheric nitrogen in the soil may explain this observation. Under an intercropping of pigeon pea with sorghum, (Egbe and Kalu (2006) and Egbe and Adeyemo (2006) found pigeon pea to fix approximately between 37.52 – 164.82 kg N ha⁻¹ farming season. In Ghana, Adjei-Nsiah (2012) estimated that pigeon pea can contribute up to 200 kg N ha⁻¹ over a period of 16 months through N-fixation. Adu Gyamfi et al. (2007) and Musokwa and Mafongoya, (2021) further attributed increase in soil N after pigeon pea cultivation to the quick decomposition of its high quality leaf litter and dead roots, which may release about 70 % of its N within a season under tropical conditions (Giller and Cadisch, 1995). The vigorous root system of pigeon pea might have also given it the capacity to explore large soil volume and recycled nutrients from deeper soil profiles (Adjei-Nsiah, 2012). Possible reduction in N losses from runoff and erosion due to the soil's protection given by the dense canopy of pigeon pea could also account for the enhancement of soil N at the end of the first season.

Soil Phosphorus

There was a drastic increase in the amount of soil available P (an increase by 11.70 mg/kg) before the start of year two. In some studies, increased soil P availability under pigeon pea was attributed to the efficient solubilisation and uptake of P from bound sources (e.g., Fe-P) by root exudates (Ae et al., 1990). Similar observation was made by Valenzuela and Smith (2002) in a maize/pigeon pea intercropping and they also attributed their observation to the ability of pigeon pea to access insoluble phosphates in soils low in P. Research in India showed that the roots of pigeon peas release piscidic acid, which reacts with iron-bound phosphate in the soil to release P (Ae et al., 1990). Enhanced P-availability may also have been as a result of secretion of enzymes

in the legume rhizosphere (Duchene et al., 2017), and enhanced arbuscular mycorrhizal colonization (Jeffries et al., 2003), all of which maximize P solubility.

Soil potassium

An increment in the amount of soil potassium (49 mg/kg to 62 mg/kg) was observed similar to what was reported by Boonchee and Anecksamphant (1993). The ability of pigeon pea to explore large soil volume and recycled nutrients from deeper soil profiles could explain this observation (Adjei-Nsiah, 2012). The high content of potassium in the plant biomass of pigeon pea (3.2 %), as observed by Boonchee and Anecksamphant (1993) may also have contributed to the rise in that of the soil.

Pigeon pea's indirect contribution to enhanced soil fertility

The dense pigeon pea canopy may protect the soil from the direct action of the sun and therefore, prevents the soil from becoming hardened (Adjei-Nsiah, 2012). The leaf litter covers the soil and may reduce soil erosion, improves water infiltration and prevents heating of the soil which enhances earthworm activity and macro fauna species richness, diversity and abundance. Its extensive root system makes soil more friable, improves its tilth, and facilitates water infiltration. Pigeon pea's association with mycorrhizal fungi plays a significant role in soil aggregate stability which helps in building up soil resistance against erosion and soil structure improvement (Peoples and Craswell, 1992).

Conclusion and Recommendation

Genotype and spacing had significant influence on the growth and yield parameters measured. Genotype L-2015-2 at 100 cm x 60 cm had the highest grain yield. The different genotypes required different spacing for their optimum yield due to difference in plant architecture, growth and branching habit. Spacing had significant influence on branching habit and number of pods per plant. It is therefore recommended that; each genotype should be matched with its preferred spacing for optimum growth and maximum grain yield. Irrespective of the genotype or spacing,

better crop growth and yield may be recorded in subsequent cropping seasons due to significant improvement in major soil chemical properties. The cultivation of pigeon pea in rotation with other nutrient demanding crops (such as cereals) could therefore be considered.

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