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.

Comment [m1]: There is no discussion or table that show the three factor interaction

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 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 P_2O_5 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 (Blume, 1985). 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 & 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, 2015) 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}) × 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) and the least significant difference at 5% probability was used for mean separation.

Results

Average monthly total rainfall (May–December) recorded was generally higher in 2020 (165.4 mm) compared with 2021 (112.0 mm). Average monthly temperature (May-December) was 28.3 °C and 28.2 °C in 2020 and 2021 cropping, respectively (Figure 1).

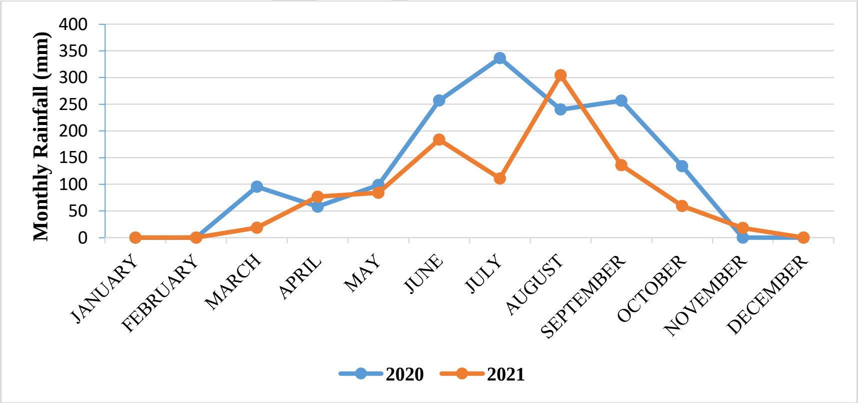

Figure 1. Monthly rainfall data for the study area for the years 2020 and 2021

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.

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

Year	pH	% O.C	% N	mg/kg P	mg/kg K	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

Crop Performance

Number of leaves per plant

Number of leaves per plant at flowering was significantly affected by the interaction of genotype and spacing in both 2020 and 2021 season Table 2 and figure 2. Number of leaves ranged between 1140 leaves plants^{-1} and 495 leaves plants^{-1} with a mean of 834.6 leaves plants^{-1} at flowering in 2020 whereas in 2021, it ranged between 1243 leaves plants^{-1} and 880 leaves plants^{-1} with a mean of 1049.9 leaves plants^{-1}. Number of leaves at flowering was significantly highest in genotype L-2015-3 at 100 cm x 60 cm compared with the other treatment combinations in 2020. On the contrary, genotype L-2015-2 at100 cm x 60cm produced significantly the most leaves at flowering 2021. However, it was significantly similar to genotypes L-2015-2 at 100 cm x 75 cm, L-2015-3 at100 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 whereas in 2021, ICP -8863 at 100 cm x 60cm and ICP -8863 at 100 cm x 30 cm had fewer number of leaves at flowering.

Comment [m2]: This paragraph is almost the same with other paragraph explaining the results of other characters. Since the table is available presenting the results it might not be necessary state the value in the table . Let the reader interpret the table.

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

Comment [m3]: It might be more clear if the table presented in a two way classification, with genotype as row and plant spacing as column and denote the values that are significantly different by rows or columns. The interaction can easily be interpreted

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	44.23	43.08	236.2	267.7	1.609	1.776

L-2015-3	912.2	1117.0	43.30	41.20	216.2	291.5	1.097	1.520
ICP-8863	676.6	894.5	40.87	35.27	253.2	289.6	0.879	0.850
SED	20.34	20.59	0.732	0.782	7.36	6.67	0.0914	0.1074
Spacing								
100 cm x 30 cm	809.4	1004.6	39.30	38.82	242.8	289.6	0.935	1.064
100 cm x 45 cm	775.0	1011.2	40.87	39.62	239.2	291.5	1.106	1.266
100 cm x 60 cm	886.9	1095.7	46.33	40.27	224.8	288.0	1.447	1.797
100 cm x 75 cm	866.9	1087.9	44.71	40.69	234.0	282.8	1.291	1.403
SED	23.48	23.77	0.845	0.903	8.50	7.70	0.1055	0.1241
Interaction								
(L-2015-2) x (100 cm x 30 cm)	881.8	1014.9	40.80	39.93	245.2	291.1	0.995	1.253
(L-2015-2) x (100 cm x 45 cm)	744.6	1065.6	39.13	40.33	227.3	277.7	1.530	1.755
(L-2015-2) x (100 cm x 60 cm)	1025.6	1242.5	50.53	46.67	239.1	301.5	2.065	2.583
(L-2015-2) x (100 cm x 75 cm)	1007.4	1229.1	46.47	45.40	233.1	291.2	1.847	1.513
(L-2015-3) x (100 cm x 30 cm)	831.2	1118.5	36.87	37.87	215.9	255.7	0.964	1.112
(L-2015-3) x (100 cm x 45 cm)	721.4	1065.9	43.87	37.53	232.0	297.7	1.016	1.312
(L-2015-3) x (100 cm x 60 cm)	1140.0	1164.5	48.13	44.67	187.6	258.3	1.304	1.972
(L-2015-3) x (100 cm x 75 cm)	956.2	1119.2	44.35	44.73	229.4	259.0	1.103	1.687
(ICP-8863) x (100 cm x 30)	715.2	880.3	40.23	38.67	267.3	322.0	0.847	0.827
(ICP-8863) x (100 cm x 45)	859.0	902.3	39.60	41.00	258.4	299.0	0.772	0.730
(ICP-8863) x (100 cm x 60)	495.0	880.0	40.33	29.47	247.7	304.3	0.972	0.837
(ICP-8863) x (100 cm x 75)	637.2	915.5	43.30	31.93	239.6	298.1	0.924	1.008
SED	40.68	41.17	1.464	1.564	14.72	13.34	0.1828	0.2149
Genotype (P<0.05)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Spacing (P<0.05)	0.001	0.001	0.001	0.213	0.199	0.706	0.001	0.001
Genotype x Spacing (P<0.05)	0.001	0.003	0.001	0.001	0.106	0.019	0.030	0.004
Mean	834.6	1049.9	42.80	39.85	235.2	288.0	1.195	1.382
CV (%)	6.0	4.8	4.2	4.8	7.7	5.7	18.7	19.0

Number of Branches per plant

Number of branches at flowering was significantly affected by the interaction of genotype and spacing in both 2020 and 2021 season (Table 2 and Figure 3). Number of branches ranged between 53.7 branches plants^{-1} and 37.7 branches plants^{-1} with a mean of 44.9 branches plants^{-1} at flowering in 2020 whereas in 2021, number of branches at flowering ranged between 56.87 branches plants^{-1} and 41.9 branches plants^{-1} with a mean of 46.8 plants^{-1}. 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. However, it was significantly similar to genotypes L-2015-3 at 100 cm x 60 cm and L-2015-2 at 100 cm x 75 cm in both 2020 and 2021 respectively. Genotype L-2015-3 at 100 cm x 30 cm had significantly fewer branches at flowering in 2020. Whereas in 2021, ICP -8863 at 100 cm x 60cm and ICP -8863 at 100 cm x 30 cm had fewer branches at flowering.

Plant Height

Plant height at physiological maturity in 2020 was significantly affected by the interaction of genotype and spacing (Tables 2 and 4). However, plant height at physiological maturity in 2020 and 2021 were not significantly affected by the interaction of genotype and spacing. Plant height ranged between 267.3 cm 187.6 cm with a mean of 235.2 cm in 2020. In 2021, plant height ranged between 322.0 cm and 255.7 cm with a mean of 288.0 cm. Genotype ICP -8863 at 100 cm x 30 cm produced significantly taller plants compared with the other treatment combinations in 2020. Genotypes L-2015-2 at 100 cm x 60 cm and L-2015-3 at 100 cm x 60 cm produced the shortest plants in 2020. Similarly, in 2021, 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.

Comment [m4]: Table 4 did not present plant height.

Comment [m5]: This statement is contradicted with the previous statement about the result in 2020:Plant height at physiological maturity in 2020 was significantly affected by the interaction of genotype and spacing

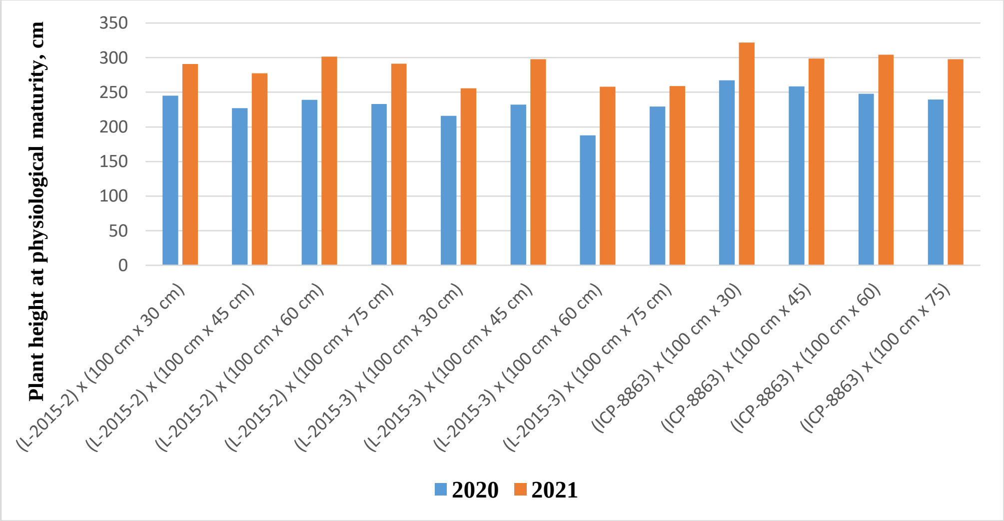

Figure 2. Effect of genotype and spacing plant height at physiological maturity in 2020 and 2021 cropping season

Leaf area index (LAI)

Leaf area index was significantly affected by the interaction of genotype and spacing in both 2020 and 2021 (Table 2). Leaf area index ranged between 2.067 and 0.77 with a mean of 1.20 in 2020 whilst in 2021, it ranged between 2.58 and 0.73 with a mean of 1.38. Genotype L-2015-3 at 100 cm x 60 had significantly the highest leaf area index in both 2020 and 2021 (Fig.). However, in 2020, it did not differ significantly from genotype L-2015-2 at 100 cm x 75 cm.

Number of pods per plant

Number of pods per plant was significantly affected by the interaction of genotype and spacing in both 2020 and 2021 (Table 3). Number of pods per plant ranged between 1869 pods plants^{-1} and 937 pods plants^{-1} with a mean of 1398 pods plants^{-1} in 2020 whereas in 2021, number of pods ranged between 2006 pods plants^{-1} and 853 pods plants^{-1} with a mean of 1407 pods plants^{-1}. Genotype L-2015-3 at 100 cm x 60 produced significantly more pods per plant in 2020 though it was significantly similar to genotype L-2015-2 at 100 cm x 75 cm. Similarly, in 2021, genotype L-2015-3 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, 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.

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

Treatments	**Number of pods per plant**		**Pod Length (cm)**		**Number of seeds per pod**		**Grain yield/plant (g)**	
	2020	2021	2020	2021	2020	2021	2020	2021
Genotypes								
L-2015-2	1542.	1583.	4.3	4.7	3.7	3.8	158.3	171.6
L-2015-3	1433.	1486.	4.6	4.4	3.4	3.5	151.6	145.3
ICP-8863	1218.	1152	4.025	3.9	3.4	3.7	135.1	110.6
SED	39.6	48.1	0.056	0.197	0.095	0.105	15.52	13.25
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	3.3	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
SED	45.7	55.5	0.065	0.228	0.109	0.122	17.92	15.30
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
SED	79.2	96.1	0.113	0.279	0.189	0.211	31.04	26.50
Genotype (P<0.05)	0.001	0.001	0.001	0.004	0.028	0.002	0.015	0.001
Spacing (P<0.05)	0.001	0.001	0.001	0.001	0.001	0.003	0.351	0.001
Genotype x Spacing (P<0.05)	0.013	0.024	0.033	0.006	0.019	0.029	0.018	0.003
Mean	1398.	1407.	4.8	4.4	3.5	3.6	148.3	142.5
CV (%)	6.9	96.1	3.1	11.2	6.5	7.2	12.4	22.8

Pod Length (cm)

Pod length was significantly influenced by the interaction of genotype and spacing in both 2020 and 2021 (Table 3). Average pod length ranged between 5.0 cm and 3.7 cm with a mean of 4.8 cm in 2020. In 2021, pod length ranged between 5.9 cm and 3.8 cm with a mean of 4.3 cm in 2021. 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, 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, genotype ICP -8863 at 100 cm x 45 cm produced significantly the shortest pods but it was statistically similar to all the treatment combinations apart from genotypes L-2015-2 at 100 cm x 60cm, L-2015-3 at 100 cm x 75 cm and L-2015-2 at 100 cm x 75 cm.

Number of seeds per pods

Number of seeds per pod was significantly affected by the interaction of genotype and spacing in both 2020 and 2021 (Table 3). Number of seeds per pod ranged between 4.2 seeds pod^{-1} and 3.2 seeds pod^{-1} with a mean of 3.5 seed pod^{-1} in 2020. Whereas in 2021, number of seeds per pod ranged between 4.4 seeds pod^{-1} and 3.2 seeds pod^{-1} with a mean of 3.6 seeds pod^{-1} in 2021. Genotype L-2015-2 at 100 cm x 60 produced significantly more seeds per pod in 2020. 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 2020, genotype L-2015-2 at 100 cm x 30 cm produced few seeds per pod but it was statistically similar to all the treatment combinations except 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, significantly fewer seeds were produced by genotype L-2015-3 at 100 cm x 45 cm. However, it did not differ significantly from all the 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.

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

Treatments	**Thousand seed weight**		**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
SED	1.117	4.061	30.3	63.7	269.2	826.4	0.492	1.199
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
SED	1.290	4.689	35.0	73.6	310.8	954.2	0.568	1.385
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
SED	2.235	3.916	60.7	127.4	538.4	1652.8	0.984	2.399
Genotype (P<0.05)	0.001	0.001	0.001	0.001	0.001	0.032	0.001	0.043
Spacing (P<0.05)	0.001	0.001	0.001	0.088	0.001	0.972	0.001	0.395
Genotype x Spacing (P<0.05)	0.001	0.001	0.001	0.001	0.001	0.184	0.001	0.005
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	9.2	21.8

Grain yield per plant (g)

Grain yield per plant was significantly influenced by the interaction of genotype and spacing in both 2020 and 2021 (Table 3). Grain yield per plant ranged between 193.1 g plants^{-1} and 118.1 g plants^{-1} with a mean of 148.3 g plants^{-1} in 2020. In 2021, grain yield per plant ranged between 284.7 g plants^{-1} and 81.1 g plants^{-1} with a mean of 142.5 g plants^{-1}. Significantly, in both 2020 and 2021, genotype L-2015-2 at 100 cm x 60 had 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.

Grain yield (kg ha^{-1})

Grain yield was significantly affected by the interaction of genotype and spacing in both 2020 and 2021 (Table 4 and Figure 3). Grain yield ranged between 1166.0 kg ha^{-1} and 391.0 kg ha^{-1} with a mean of 904.0 kg ha^{-1} in 2020. Whilst grain yield ranged between 2311 kg ha^{-1} and 1217 kg ha^{-1} with a mean of 1514.0 kg ha^{-1} in 2021. Significantly, genotype L-2015-2 at 100 cm x 60 had the highest grain yield in both 2020 and 2021. However, in 2020, 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.

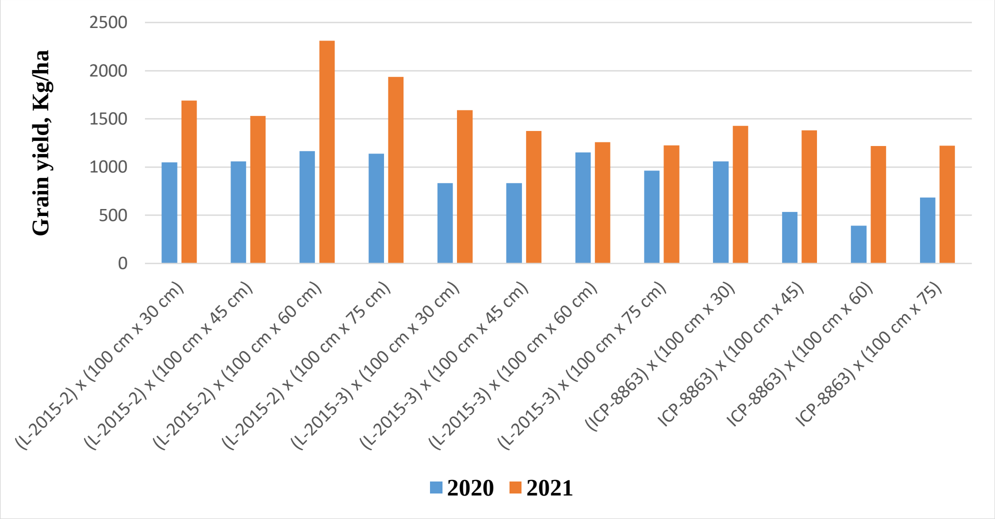

Figure 3. Effect of genotype and spacing on grain yield per hectare in 2020 and 2021 cropping season.

Biomass yield (kgha^{-1})

Biomass yield was significantly affected by the interaction of genotype and spacing in both 2020 (Table 4). However, in 2021 biomass yield was significantly affected by genotype main effect. Biomass yield ranged between 9000.0 kg ha^{-1} and 3067.0 kg ha^{-1} with a mean of 6573.0 kg ha^{-1} in 2020. Although not statistically different, biomass yield ranged between 13400 kg ha^{-1} and 8033 kg ha^{-1} with a mean of 10022.0 kg ha^{-1} in 2021. Significantly, genotype ICP -8863 at 100 cm x 30 cm x 60 had the highest biomass yield in both 2020. However, it was significantly similar to genotypes ICP -8863 at 100 cm x 45 cm and L-2015-2 at 100 cm x 30 cm. Genotype ICP -8863 at 100 cm x 75 cm obtained the lowest biomass yield. In 2021, genotype L-2015-2 significantly had the highest biomass yield but it did not differ statistically from genotype ICP -8863. The lowest biomass yield was obtained from genotype L-2015-3.

Thousand seed weight, (g)

Thousand seed weight was significantly affected by the interaction of genotype and spacing in both 2020 and 2021 (Table 4). Thousand seed weight ranged between 96.5 g and 63.3 g with a mean of 72.7 g in 2020. Whilst thousand seed weight ranged between 102.8 g and 63.7 g with a mean of 79.5 in 2021. 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. Genotype L-2015-3 at 100 cm x 30 cm had significantly the lowest thousand seed weight in 2020 whereas in 2021, genotype ICP -8863 at 100 cm x 60 cm had the significantly the lowest thousand seed weight.

Harvest index

Harvest was significantly affected by the interaction of genotype and spacing in both 2020 and 2021 (Table 4). Harvest index ranged between 18.1 % and 5.7 % with a mean of 12.6 % in 2020 whilst grain yield ranged between 21.3 % and 10.9 % with a mean of 13.5 % in 2021. 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, it was 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.

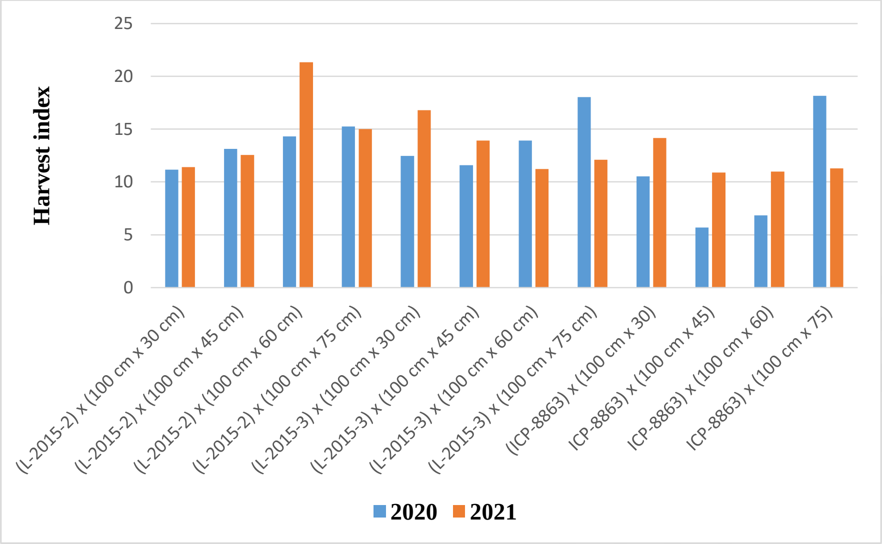

Figure 4. Effect of genotype and spacing on harvest index in 2020 and 2021 cropping season.

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. 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 6 0 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 Hector and Smith (2007) 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.

Reference

Abubaker, S. (2008). Effect of plant density on flowering date, yield and quality attribute of bush beans (Phaseolus Vulgaris L.) under Center Pivot Irrigation System. *American Journal of Agricultural and Biological Science*, *3*(4), 666–668. https://doi.org/10.3844/AJABSSP.2008.666.668

Adjei-Nsiah, S. (2012). Role of Pigeonpea Cultivation on Soil Fertility and Farming System Sustainability in Ghana. *International Journal of Agronomy*, *2012*, 1–8. https://doi.org/10.1155/2012/702506

Adu-Gyamfi JJ, Myaka FA, Sakala WD, Odgaard R, Vesterager JM, Hogh-Jensen H (2007) Biological nitrogen fixation and nitrogen and phosphorus budgets in farmer-managed intercrops of maize-pigeonpea in semi-arid southern and eastern Africa. Plant Soil 295:127–213

Ae, N., Arihara, J., Okada, K., Yoshihara, T., Johansen, C. (1990). Phosphorus uptake by pigeon pea and its role in cropping systems of the Indian subcontinent. *Science (New York, N.Y.)*, *248*(4954), 477–480. https://doi.org/10.1126/science.248.4954.477

Amoako, O. A., Adjebeng-Danquah, J., Bidzakin, J. K., Abdulai, H., Kassim, B. Y., Owusu, E. Y and Alhassan, R. (2020). Response of Improved Cowpea Varieties to Spacing in the Guinea Savannah Ecology of Ghana. *Journal of Ghana Science Association*, *19*(1).

Bakry BA, Elewa TA, El Karamany MF, Zeidan MS, Tawfik MM (2011) Effect of row spacing on yield and its components of some faba bean varieties under newly reclaimed sandy soil condition. World J Agric Sci 7: 68-72.

Blume, H. -P. (1985). Page, A. L., R. H. Miller and D. R. Keeney (Ed., 1982): Methods of soil analysis ; 2. Chemical and microbiological properties, 2. Aufl. 1184 S., American Soc. of Agronomy (Publ.), Madison, Wisconsin, USA, gebunden 36 Dollar. . *Zeitschrift Für Pflanzenernährung Und Bodenkunde*, *148*(3), 363–364. https://doi.org/10.1002/JPLN.19851480319

Boonchee, S: and C. Anecksamphant, 1993. "Sustaining Soil Organic Matter for Upland Rice Production in Northern Thailand". Proc. Int Symposium on Soil Organic Matter Dynamics and Substainability of Tropical Agric. Jointly organized by the laboratory of Soil fertility *and soil Biology, Katholieke Universitert Leuven (K.U. Leuven) and 1.1.1..A: 155 – 161, Leuven, Belgium.*

Bray, R. H., Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science*, *59*(1), 39–45. https://doi.org/10.1097/00010694-194501000-00006

Bremner, J. M., Keeney, D. R. (1965). Steam distillation methods for determination of ammonium, nitrate and nitrite. *Analytica Chimica Acta*, *32*(C), 485–495. https://doi.org/10.1016/S0003-2670(00)88973-4

Chandhla, J. (2005). *Optimisation of dry bean (Phaseolus vulgaris L.) seed production under greenhouse conditions*. https://repository.up.ac.za/handle/2263/29285

D.K. Chandraker, B. T., Sushil Kumar Bhagat, T. R. B., v, M. (2017). Effect of Different Genotype and Planting Geometry on Growth and Productivity of Rabi Season Pigeon Pea (Cajanus cajan L.). *International Journal of Current Microbiology and Applied Sciences*, *6*(3), 2188–2195. https://doi.org/10.20546/IJCMAS.2017.603.249

Deng, J., Ran, J., Wang, Z., Fan, Z., Wang, G., Ji, M., Liu, J., Wang, Y., Liu, J., Brown, J. H. (2012). Models and tests of optimal density and maximal yield for crop plants. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(39), 15823–15828. https://doi.org/10.1073/PNAS.1210955109

Duchene, O., Vian, J. F., and Celette, F. (2017). Intercropping with legume for agroecological cropping systems: Complementarity and facilitation processes and the importance of soil microorganisms. A review. *Agriculture, Ecosystems and Environment*, *240*, 148–161. https://doi.org/10.1016/j.agee.2017.02.019

Egbe, O. M., and Adeyemo, M. O, 2006, Estimation of the effect of intercropped pigeonpea on the yield and yield components of maize in Southern Guinea Savanna of Nigeria. Journal of Sustainable Development in Agriculture and Environment 2 (1), 107-118.

Egbe, O. M., and Kalu, B. A., 2006, Farming Systems Study: Participatory Rural Appraisal of pigeonpea cropping systems in Southern Guinea Savanna of Nigeria., Journal on Environment

Egbe, O. M.. and Bar-Anyam, M. N, 2010, Pigeonpea/sorghum intercropping in Southern Guinea Savanna: effects of planting density of pigeonpea, Nature and Science, 8 (11), 156-167.

FAO-UNESCO (1977) FAO-UNESCO Soil Map of the World, Vol. VI. Africa. UNESCO, Paris, 299. - References - Scientific Research Publishing. (n.d.).

Giller, K. E., & Cadisch, G. (1995). Future benefits from biological nitrogen fixation: An ecological approach to agriculture. *Management of Biological Nitrogen Fixation for the Development of More Productive and Sustainable Agricultural Systems*, 255–277. https://doi.org/10.1007/978-94-011-0055-7_13

Hector V and J Smith. 2007. Green manure crops: pigeon pea: sustainable agriculture green manure crops. Cooperative extension services. College of tropical and human resources, University of Hawaii. - Search. (n.d.).

Jeffries, P., Gianinazzi, S., Perotto, S., Turnau, K., and Barea, J. M. (2003). The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. *Biology and Fertility of Soils*, *37*(1), 1–16. https://doi.org/10.1007/S00374-002-0546-5

Kumar, P., Pal, M., Joshi, R., and Sairam, R. K. (2013). Yield, growth and physiological responses of mung bean [Vigna radiata (L.) Wilczek] genotypes to waterlogging at vegetative stage. *Physiology and Molecular Biology of Plants : An International Journal of Functional Plant Biology*, *19*(2), 209–220. https://doi.org/10.1007/S12298-012-0153-3

Kumar, V., Dhankhar, S., Vilas, C. A., and Yadav, N. (2016). Effect of spacing on growth and yield parameters of two varieties of okra, Abelmoschus esculantus (L) Moench. *Undefined*.

Musokwa, M., and Mafongoya, P. L. (2021). Effects of improved pigeonpea fallows on biological and physical soil properties and their relationship with maize yield. *Agroforestry Systems*, *95*(2), 443–457. https://doi.org/10.1007/S10457-021-00598-7

Nagaraj B. Maheshwara Babu, B. S. Polisgowdar, M. S. Ayyanagowdar, D. Krishnamurthy, Kavita Kandpaland and G. Ramesh. Influence of Chlorophyll Content and Leaf Area Index on Growth of Pigeonpea. Int.J.Curr.Microbiol.App.Sci (2019) Special Issue-9: 43-51

Ndiaga, C. (2001). Genotype x row spacing and environment interaction of cowpea in semi-arid zones. African Crop Science Journal, 9(2):359–367. Nelson, D. W., and Sommers, L. E. (2015). *Total Carbon, Organic Carbon, and Organic Matter*. 539–579. https://doi.org/10.2134/AGRONMONOGR9.2.2ED.C29.

Peoples, M. B., and Craswell, E. T. (1992). Biological nitrogen fixation: Investments, expectations and actual contributions to agriculture. *Plant and Soil*, *141*(1–2), 13–39. https://doi.org/10.1007/BF00011308

Robe Elema, Alamu Tolosa, Frezer Yemane. Effects of Pigeon Pea (Cajanus cajan) Intercropping on Sorghum Crop Production and Soil Fertility Level in Case of Harari Regional State (Erer Research on Station). Agriculture, Forestry and Fisheries. Vol. 11, No. 1, 2022, pp. 15-20. doi: 10.11648/j.aff.20221101.1.

Sharma S, Agarwal N, Verma P (2011) Pigeon pea (Cajanus cajan L.): a hidden treasure of regime nutrition. J Funct Environ Botany 1(2):91–101.

Shenkute B, Hassen A, Ebro A, Amen N (2013) Performance of Arsi-Bale kids supplemented with graded levels of pigeon pea in dry season in Mid Rift valley of Ethiopia. Afr J Agric Res 8(20):2366–2370.

Shiferaw Tadesse and Zerihun Abebe (2019) Effect of Soil Incorporated Pruned Pigeon pea and Nitrogen on System Productivity in Maize/Pigeon pea Intercropping. Ethiop. J. Agric. Sci. 29 (1) 73-83 (2019).

Siddique, K. H. M., Johansen, C., Turner, N. C., Jeuffroy, M. H., Hashem, A., Sakar, D., Gan, Y., and Alghamdi, S. S. (2012). Innovations in agronomy for food legumes: a review. *Agron Sustain Dev*, *32*(1), 45–64. https://doi.org/10.1007/s13593-011-0021-5

Snapp, S. S., Jones, R. B., Minja, E. M., Rusike, J., & Silim, S. N. (2003). Pigeon Pea for Africa: A Versatile Vegetable--And More. *Undefined*, *38*(6), 1073–1079. https://doi.org/10.21273/HORTSCI.38.6.1073

Tigga, B., Chandraker, D. K., Banjara, T. R., Bhagat, S. K., and Dev, M. (2017). Effect of Different Genotype and Planting Geometry on Growth and Productivity of Rabi Season Pigeon Pea (Cajanus cajan L.). *Int.J.Curr.Microbiol.App.Sci*, *6*(3), 2188–2195. https://doi.org/10.20546/ijcmas.2017.603.249