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RESEARCH ARTICLE

Synergistic effects of planting geometry and integrated nutrient management on pigeon pea growth, yield and soil health

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Abstract

A field experiment was conducted during the Kharif season of 2023 at the research farm of Lovely Professional University, Phagwara, Punjab, to evaluate the effect of different spacing (P) and nutrient sources (N) on pigeon pea growth and yield. The experiment consisting four different spacings *viz.* P_1- (conventional sowing at 50 cm × 25 cm), P_2- (30 cm × 25 cm), P_3- raised bed (67.5 cm), P_4- (60 cm × 20 cm) with four nutrient sources viz. N_1- (control), N_2- (100 % RDF-recommended dose of fertilizer), N_3- (100 % organic), N_4- (50 % N RDF + 50 % N Farmyard manure, FYM) was laid in split-plot design and replicated thrice. The results revealed that pigeon pea performed better when sown on raised bed in terms of plant height, number of primary and secondary branches, dry matter accumulation, chlorophyll index, number of pods plant^{-1}, seeds pod^{-1}, pod length, seed index, seed yield, stalk yield and harvest index while narrow spacing of 30 cm × 25 cm recorded maximum leaf area index (LAI). Similarly, the application of balanced nutrition showed maximum plant height, a greater number of primary and secondary branches, higher LAI, dry matter and chlorophyll index. Maximum number of pods plant^{-1}, seeds pod^{-1}, pod length, seed index, seed yield and stalk yield along with a maximum harvest index. Whereas the lowest values for growth and yield parameters were exhibited by narrower spacing P_2 and N_1 with respect to main and sub plot.

Keywords: biological ploughing; crop intensification; integrated nutrient management; sustainable crop production

Introduction

Pigeon pea is a versatile and resilient crop that can thrive in a wide range of environmental conditions including tropical and subtropical regions. This crop performs well both as a monocrop and in intercropping systems (1). The essential component of Indian diets, dal, is pulse grain in form of splits as a high-protein (20-30 %) source. The pigeon pea is the second most important pulse crop in India after chickpea in terms of area and production, cultivated over an area of 1.8 million hectares with a production of 2.1 million tons during 2020-21. As a 3F crop, pigeon pea is widely used for its splits as food, leaves and stems as fodder and stalks as fuel. Pigeon peas contain 55.7, 21.0, 5.1, 2.3 and 8.2 % of their weight in carbohydrates, protein, soluble sugar, fat and minerals and crude fiber, respectively. Being a deep-rooted crop, it serves as a "biological plough." Extensive ground cover by pigeon pea prevents soil erosion due to wind and water which encourages the infiltration of rainwater and smothers the weeds. The plant's natural ability to fix atmospheric nitrogen contributes to betterment of soil fertility, productivity and structure by recycling of nutrients, high litter fall and soil loosening (2).

Any crop's growth and development are influenced by the presence of various growth factors, such as light, temperature, humidity and the availability of nutrients. The genetic make-up and existing environment play a major role in the production, accumulation and translocation of metabolites from source to sink. The efficiency of this process is increased by using appropriate agronomic management, which enables the exploitation of a variety of resources to increase production. Main agronomic manipulations affecting crop development and yield include timing of sowing or planting techniques, maintenance of plant population and planting geometry. Pigeon pea yield is a combined result of various yield -attributing characteristics and plant population, which is in turn influenced by planting geometry.

Organic input must always be used in sustainable production strategies. It is well known that using organic manure helps to improve plant nutrition and soil health. FYM (farmyard manure) is considered as an important source of adding organic matter and nutrients to the soil. These nutrients are available to the plants by decomposition of FYM by microorganisms. However, organic manures cannot provide crops with all the nutrients they need due to their restricted availability (3). Integrated nutrient management (INM) practices, which can balance the cost and health scenarios, are currently receiving more attention. According to reports, integrating inorganic, organic and bio-fertilizers is crucial for increasing pigeon pea yield and lowering production cost (4).

The objective of the study was to evaluate the influence of different planting geometries and nutrient management practice on growth, the yield and soil physico-chemical properties of pigeon pea.

Material and Methods

Site of the field experiment

A field experiment was conducted at an agricultural research farm at Lovely Professional University, Phagwara (Punjab) during the kharif season of 2023 to evaluate the performance of pigeon pea in response to varying spacing and nutrient sources. The site of the experimental plot falls under the subtropical category and the rainfall during the crop growing season was recorded as 486.1 mm. Weather details were collected from the Lovely Professional University weather observatory to assess the environmental conditions and their possible effect on plant growth during the study period. Temperature (˚C), dew point (˚C), humidity (%), wind speed (mph) and precipitation (inch) were recorded and presented as Standard Meteorological Week (SMW) wise meteorological data in Fig. 1.

Details of experimental design

The experimental design was laid out in a split plot design with varying spacings (P) as main factor [P_1- conventional sowing at 50 cm × 25 cm, P_2- 30 cm × 25 cm, P_3- raised bed (67.5 cm), P_4- 60 cm × 20 cm and nutrient sources (N) as sub factor [N_1-control, N_2- RDF (15 kg N, 40 kg P_2O_5), N_3- organic (100 % N from FYM @ 3t ha^{-1}), N_4- INM (50 % N RDF + 50 % N FYM]. A total of 16 treatment combinations were used which were replicated thrice. The seeds of pigeon pea variety AL882 obtained from PAU-Punjab Agriculture University Ludhiana were treated with rhizobium culture and dibbled (single seed $hole^{-1}$) manually in a plot area of 6.0 × 5.0 m with the spacing followed as per the treatment where, 50 cm × 25 cm plot maintained10 rows, 30 cm × 25 cm maintained 18 rows, raised bed (67.5 cm) had 4 beds with two rows each and 60 cm × 20 cm contained 8 rows in a plot size of 6.0 ×5.0 m. FYM was incorporated 2 weeks before sowing for its proper decomposition as per treatment. One pre sowing irrigation was applied to the crop five days before sowing to maintain the optimum moisture in the field followed by a post sowing irrigation about 9-11 days after sowing.

Leaf area index

Leaf area index was determined by dividing the total leaf area per unit ground area. The following formula was used to compute LAI (5):

$$LAI = \frac{A_L}{A_G} \quad \text{Eqn. 1}$$

Where, A_L is total leaf area measured by multiplying leaf length to leaf width, A_G is ground area occupied by the plant

Harvest Index (%)

Harvest index expresses the ratio of economic yield to the above ground biomass. It is estimated using the following formula (6):

$$hI = \frac{EY}{BY} \times 100 \quad \text{Eqn. 2}$$

Where, EY is the economic yield; BY is the biological yield

Bulk density (g cm^{-3})

Bulk density is the measure of the mass of soil per unit volume which is estimated using the core sampler method and evaluated by putting the values in the following formula (7):

$$B.D = \frac{\text{mass of soil (g)}}{\text{volume of soil (cm}^{-3}\text{)}} \quad \text{Eqn. 3}$$

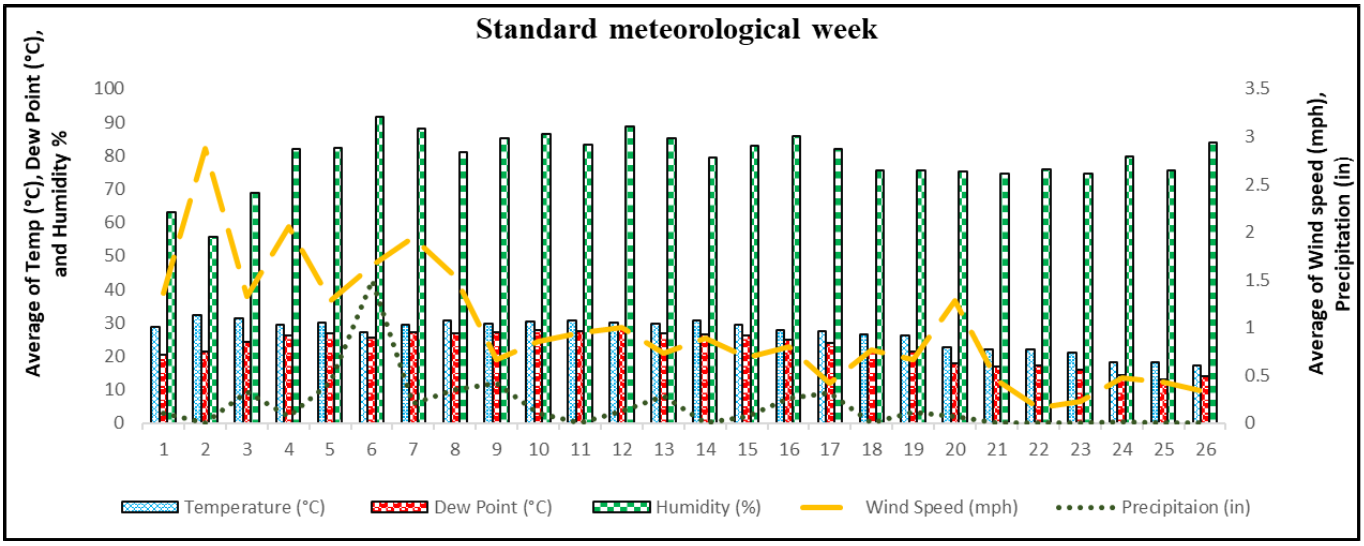

Fig. 1. Standard week wise meteorological data during the crop growth period June 2023 to November 2023.

Soil analysis

Initial soil samples were collected from 0-15 cm depth for the analysis. The soil of the experimental field was sandy loam with low organic carbon (0.31 %) and low available nitrogen (N) (139.76 kg ha^{-1}), moderately available phosphorus (P) (24.14 kg ha^{-1}) and high available potassium (K) (202.61 kg ha^{-1}). The soil was slightly alkaline with a pH of 7.9 and electrical conductivity was 0.37 dSm^{-1}. For the estimation of soil pH (glass electrode pH meter model no. *µ pH* System 361) and EC tested with EC meter (model no. Conductivity TDS meter 308). Soil organic carbon was determined using Walkley and Black's rapid titration method (8), while available N was estimated by alkaline potassium permanganate method (9). As for soil available P and K sodium bicarbonate extractable method and 1N ammonium acetate extractable method, respectively was followed (10).

Data collection

For data collection at vegetative, flowering and maturity stages have been chosen. Growth parameters viz. plant height (cm), number of primary and secondary branches, LAI, dry matter accumulation (g) and chlorophyll index (SPAD), three healthy plants were selected and tagged from each plot. Their average was taken for compilation of results later. Similarly, at maturity yield attributing (number of pods plant^{-1}, pod length (cm), number of seeds pod^{-1}, seed index (g) and yield (seed and haulm yield in kg ha^{-1}), the crop was harvested with a sickle, tied and tagged in bundles which were later threshed after sun drying. All the operations were performed manually plot wise. As for post-harvest studies, soil samples were collected from each plot after harvesting and tested in laboratory for further analysis.

Statistical analysis

The significant difference between two treatments were estimated using two factor analysis for split plot design in OPSTAT software (HAU) at P= 0.05. The method of variance was described elsewhere (11).

Results

Different spacing and nutrient management practices significantly influenced the growth and yield of pigeon pea during the experimental year

Effect of different spacing and nutrient management on growth, yield parameters and yield of pigeon pea

Plant height (cm)

The observed differences in the height of plants were statistically significant as indicated by the data presented in Table 1. Among all the treatments, maximum (174.6 cm) plant height was observed in raised bed treatment at harvest which was followed by a wider spacing of rows (50 cm × 25 cm) (169.2 cm) while minimum (165.86 cm) plant height was observed in close spacing of *viz.*30 cm × 25 cm. Among nutrient management practices 50 % N RDF + 50 % N FYM (176.08 cm) performed significantly superior to all other treatments and control recorded the minimum (161.14 cm) plant height. The interaction between main and sub factors were found to be significant at harvest with P_3- (raised bed 67.5 cm) performing best (182.6 cm) with N_4- (50 % N RDF + 50 % N FYM).

Number of primary and secondary branches

The data related to the number of primary and secondary branches is presented in Table 1, which shows a significant difference in treatments. Results revealed that the highest (16.73, 14.47) number of primary and secondary branches were observed in raised beds which was closely followed by a slightly wider spacing i.e.50 cm × 25 cm (14.79, 13.73). Among nutrient management practices, a greater (17.58, 15.83) number of primary and secondary branches were recorded in 50 % N RDF + 50 % N FYM which was significantly superior to other treatments while control bearing least (10.79, 9.62) number of branches at harvest. The interaction between main and sub factors was found to be non-significant for both primary and secondary branches.

Dry matter accumulation (g plant^{-1})

Data pertaining to dry matter accumulation revealed that raised bed planting produced maximum (117.48 g plant^{-1}) dry matter with pigeon pea sown on raised bed while narrow spacing which is 30 cm × 25 cm recorded minimum (91.07g plant^{-1}) dry matter. Dry matter accumulation was significantly affected by nutrient management practices with highest (121.91 g plant^{-1}) dry matter in 50 % N RDF + 50 % N FYM and lowest (85.33 g plant^{-1}) dry matter was recorded in control.

The interaction between spacing and nutrient management were found to be significant and pigeon pea sown on raised bed exhibited showed the highest performance (132.64 g plant^{-1}) performance with the application of 50 % N RDF + 50 % N FYM while narrow spaced pigeon pea i.e. 30 cm × 25 cm performed inferior (76.93 g plant^{-1}) when no fertilizer was given to the crop.

Leaf area index (LAI)

The leaf area index of pigeon pea was significantly influenced by different spacing and nutrient management. The highest (3.1) leaf area index was observed in narrow spacing which was significantly superior to all other treatments with lowest (1.99) LAI in wider spacing 50 cm × 20 cm. In terms of nutrient management practices 50 % N RDF + 50 % N FYM showed significant superiority (2.4) among all the treatments while lowest (1.99) LAI was observed in control. The interaction between different spacing and nutrient management was found to significant in terms of LAI with highest (3.54) LAI being recorded in narrow spaced treatment combined with 50 % N RDF + 50 % N FYM.

Chlorophyll index (SPAD- Soil plant analysis development)

It is evident from the data shown in Table 1 that chlorophyll was significantly affected by different spacing and nutrient management. Raised bed treatment recorded the highest (44) chlorophyll index while the treatment spaced at 30 cm × 25 cm observed the lowest (35.25) value of SPAD. In terms of nutrient management, 50 % N RDF + 50 % N FYM exhibited the highest (42.73) SPAD with control bearing the lowest (34.4) value.

The interaction between the spacing and nutrient management with respect to SPAD at harvesting stage of pigeon pea was found to be significant and i.e. highest (46.86) SPAD was recorded when the crop was sown on raised bed with 50 % N RDF + 50 % N FYM.

Table 1. Effect of spacing and nutrient management on growth of pigeon pea

	Plant height (cm)	Primary branches	Secondary branches	Dry matter accumulation (g plant^{-1})	LAI	Chlorophyll index (SPAD)
Treatments	At harvest	At harvest	At harvest	At harvest	At harvest	At harvest
Planting pattern (cm)						
P_1- 50 × 25	169.20	14.79	13.73	108.869	1.99	41.78
P_2- 30 × 25	165.86	11.53	11.10	91.017	3.108	35.25
P_3- Raised bed (67.5 cm)	174.6	16.73	14.47	117.482	2.828	44
P_4- 60 × 20	167.25	13.25	12.69	105.577	2.013	37.06
SE(m) ±	0.26	0.34	0.20	0.98	0.048	0.55
CD (p=0.05)	0.93	1.21	0.72	3.457	0.168	1.81
Nutrient source						
N_1-Control	161.14	10.79	9.62	85.338	2.243	35.4
N_2- 100 % RDF (15 kg N, 40 kg P_2O_5, 30 kg K_2O)	172.46	15.84	14.22	113.501	2.535	41.13
N_3-Organic (FYM @ 3t ha^{-1})	167.30	12.09	12.32	102.19	2.433	38.83
N_4 - 50 % RDF + FYM @ 1.5 t ha^{-1}	176.08	17.58	15.83	121.916	2.728	42.73
SE (m) ±	0.41	0.24	0.39	1.092	0.021	0.76
CD (p=0.05)	1.20	0.72	1.15	3.208	0.063	2.24
P × N						
Factor (B) at same level of A	2.47	NS	NS	6.689	0.141	4.61
Factor (A) at same level of B	2.28	NS	NS	6.523	0.199	4.28

Effect of different spacing and nutrient management on yield attributing characters and yield of pigeon pea

Yield attributing characters

As per the data pertained in Table 2, the number of pods plant^{-1} were significantly influenced by various spacing and nutrient management during the year of study. P_3 i.e. raised bed treatment showed significantly higher (98.85) number of pods plant $^{-1}$which was closely followed by P_1 i.e. 50 cm × 25 cm (97.27) while lowest (82.76) number of podsplant^{-1}were found in P_2- (30cm × 25cm). Other yields attributing characters such as number of seeds pod^{-1}and seed index were also found to be significant when subjected to different spacings and exhibited maximum (3.81) number of seeds pod^{-1}, maximum (5.24 cm) pod length and highest (10.77 g) seed index in P_3 i.e. raised bed treatment. Regarding nutrient management, N_4*viz.* 50 % N RDF + 50 % N FYM showed significantly greater (106.65) number of pods plant^{-1} with lowest (72.42) in control along with highest (3.98) number of seeds pod^{-1}, maximum (5.2 cm) pod length and seed index (11.0 g).

Seed yield (kg ha^{-1})

The effect of different plant spacing on the yield of pigeon pea is presented in Table 3. The results indicated that there was a significant difference between all the treatments. Raised bed (P_3) treatment exhibited the highest (1188.23 kg ha^{-1}) seed yield that was significantly superior to all other treatments and was closely followed by P_1viz. 50 cm × 25 cm (1147.75 kg ha^{-1}). The lowest (968.18 kg ha^{-1}) seed yield was observed in narrow spacing i.e. 30 cm × 25 cm. While, in case of nutrient management practices, the combination of 50 % N RDF + 50 % N FYM was identified as the best treatment which has highest (1331.75 kg ha^{-1}) seed yield. The lowest (860.4 kg ha^{-1}) seed yield was recorded in control.

Haulm yield (kg ha^{-1})

Data shown in Table 3 revealed that haulm yield was significantly affected by various spacing. Highest (4961.75 kg ha^{-1}) haulm yield was observed in raised bed while less spacing of 30 cm × 25 cm recorded the lowest (4254.17 kg ha^{-1}) among all other treatments. Among different nutrient sources, highest (5547.42 kg ha^{-1}) haulm yield was recorded in 50 % N RDF + 50 % N FYM while control exhibited the lowest (3812.17 kg ha^{-1}) haulm yield.

Results exhibited a significant interaction between spacing and nutrient management. Number of pods plant^{-1}, seed yield and haulm yield were found to be maximum (111.9, 1436.67, 6004.17 kg ha^{-1}) at raised bed sown pigeon pea with 50 % N RDF and 50 % N FYM respectively.

Biological yield (kg ha^{-1})

Biological yield was significantly affected by the different spacing and nutrient management. Maximum (6149.98 kg ha^{-1}) biological yield was observed in raised bed treatment while narrow spacing of 30 cm × 25 cm recorded the minimum (5222.35 kg ha^{-1}) biological yield. INM (50 % N RDF + 50 % N FYM) exhibited the highest (6879.17 kg ha^{-1}) biological yield with control bearing the lowest (4672.57 kg ha^{-1}).

Harvest index (%)

Harvest index represents the proportion of assimilate distribution between economic and biological yield. Based on the data presented in Table 3, maximum (19.32 %) harvest index was recorded in P_3 (raised bed) while minimum (18.54 %) harvest index was observed in narrow spaced treatment *viz.* P_2. In terms of different nutrient management practices INM (50 % N RDF + 50 % N FYM) exhibited the maximum (19.47 %) harvest index with lowest (18.41 %) in control.

Table 2. Effect of spacing and nutrient management on yield attributes of pigeon pea

Treatments	Yield attributing characters			
	Number of pods plant^{-1}	Number of seeds pod^{-1}	Pod length (cm)	Seed index (g)
Planting pattern (cm)				
P_1- 50 × 25	97.27	3.61	4.68	10.42
P_2- 30 × 25	82.76	2.82	4.04	9.92
P_3- Raised bed (67.5 cm)	98.85	3.81	5.24	10.77
P_4- 60 × 20	93.73	3.38	4.27	10.18
SE(m) ±	0.21	0.11	0.05	0.09
CD (p=0.05)	0.74	0.41	0.20	0.32
Nutrient source				
N_1–Control	72.42	2.87	3.99	9.43
N_2- 100 % RDF (15 kg N, 40 kg P_2O_5, 30 kg K_2O)	100.78	3.52	4.59	10.57
N_3-Organic (FYM @ 3t ha^{-1})	92.76	3.25	4.42	10.29
N_4- 50 % RDF + FYM @ 1.5 t ha^{-1}	106.65	3.98	5.24	11.00
SE (m) ±	0.48	0.07	0.08	0.12
CD (p=0.05)	1.40	0.22	0.24	0.37
P × N				
Factor (B) at same level of A	2.85	NS	NS	NS
Factor (A) at same level of B	2.54	NS	NS	NS

Table 3. Effect of spacing and nutrient management on yield of pigeon pea

Treatments	Yield (kg ha^{-1})			
	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Planting pattern (cm)				
P_1- 50 × 25	1147.75	4827.67	5975.42	19.16
P_2- 30 × 25	968.18	4254.17	5222.35	18.54
P_3- Raised bed (67.5 cm)	1188.23	4961.75	6149.98	19.32
P_4- 60 × 20	1082.10	4621.83	5703.93	18.91
SE(m) ±	7.32	30.26	32.08	0.14
CD (p=0.05)	25.85	106.75	113.18	0.49
Nutrient source				
N_1– Control	860.4	3812.17	4672.57	18.41
N_2- 100 % RDF (15 kg N, 40 kg P_2O_5, 30 kg K_2O)	1168.57	5069.33	6237.90	18.79
N_3- Organic (FYM @ 3t ha^{-1})	1025.55	4236.50	5262.05	19.34
N_4 -50 % RDF + FYM @1.5 t ha^{-1}	1331.75	5547.42	6879.17	19.47
SE(m) ±	7.10	32.17	30.09	0.18
CD (p=0.05)	20.84	94.48	88.35	0.53
P × N				
Factor (B) at same level of A	43.89	197.62	186.48	NS
Factor (A) at same level of B	44.25	194.75	189.64	NS

The interaction effect of spacing and nutrient management was found to be non- significant with respect to harvest index.

Effect of different spacing and nutrient management on soil physico-chemical properties

pH and Electrical conductivity (dSm^{-1})

Results revealed that different spacing and nutrient management did not significantly effect on soil pH and EC (electrical conductivity) data shown in Table 4.

Soil organic carbon (%)

Soil organic carbon was significantly affected by various spacing. Highest (0.417 %) organic carbon was found in raised bed treatment while narrower spacing of 30cm × 25 cm recorded the lowest (0.354 %) organic carbon after harvest. Among nutrient sources, 100 % FYM exhibited the highest (0.412 %) soil organic carbon with control being the lowest (0.356 %) significantly in Table 4.

Bulk density (g cm^{-3})

Bulk density was found to be not significantly affected by various spacing and nutrient sources shown in Table 4. Among all the treatments lowest bulk density (1.351 g cm^{-3}) was found in raised bed whereas highest (1.359 g cm^{-3}) bulk density was recorded in narrower spacing of 30cm × 25 cm. N_3 *viz.* 100 % FYM exhibited the lowest (1.322 g cm^{-3}) bulk density while control showed the maximum (1.366 g cm^{-3}) bulk density.

Soil available nutrients (kg ha^{-1})

Data shown in Table 5 revealed soil available nutrients, i.e. nitrogen, phosphorus and potassium, were significantly influenced by various spacing and nutrient management practices. The highest (161.65 kg ha^{-1}) amount of available nitrogen was recorded in raised bed while lowest (154.27 kg ha^{-1}) exhibited by the narrow spacing of 30cm ×25cm. As in case of available phosphorus and potassium with respect to varied spacing, raised bed showed maximum (25.28 and 217.0 kg ha^{-1})

Table 4. Effect of planting patterns and nutrient management on soil properties of pigeon pea

Treatments	Soil properties			
	Soil pH	EC (mmhoscm^{-1})	OC (%)	B.D (gcm^{-1})
Planting pattern (cm)				
P_1- 50 × 25	7.867	0.373	0.413	1.363
P_2- 30 × 25	7.85	0.362	0.354	1.359
P_3- Raised bed (67.5 cm)	7.928	0.358	0.417	1.351
P_4- 60 × 20	7.867	0.356	0.339	1.362
SE(m) ±	0.03	0.001	0.001	0.001
CD (p=0.05)	NS	NS	0.003	NS
Nutrient source				
N_1– Control	7.85	0.348	0.356	1.366
N_2- 100 % RDF (15 kg N, 40 kg P_2O_5, 30 kg K_2O)	7.883	0.368	0.374	1.364
N_3 – Organic (FYM @ 3t ha^{-1})	7.878	0.354	0.412	1.348
N_4 - 50 % RDF + FYM @1.5 t ha^{-1}	7.9	0.378	0.382	1.358
SE(m) ±	0.054	0.002	0.001	0.002
CD (p=0.05)	NS	NS	0.002	NS
P × N				
Factor (B) at same level of A	NS	NS	0.005	NS
Factor (A) at same level of B	NS	NS	0.005	NS

Table 5. Effect of spacing and nutrient management on available soil nutrients of pigeon pea

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Planting pattern (cm)			
P_1- 50 × 25	158.32	24.96	210.216
P_2- 30 × 25	154.27	23.92	203.305
P_3- Raised bed (67.5 cm)	161.65	25.28	217.009
P_4- 60 × 20	150.89	24.25	207.011
SE(m) ±	0.21	0.21	0.798
CD (p=0.05)	0.75	0.75	2.817
Nutrient source			
N_1- Control	143.37	21.92	196.306
N_2- 100 % RDF (15 kg N, 40 kg P_2O_5, 30 kg K_2O)	154.45	24.66	204.679
N_3 - Organic (FYM @ 3t ha^{-1})	158.85	25.41	213.863
N_4 - 50 % RDF + FYM @1.5 t ha^{-1}	168.46	26.43	222.693
SE(m) ±	0.24	0.19	0.629
CD (p=0.05)	0.72	0.58	1.846
P × N			
Factor (B) at same level of A	1.50	NS	NS
Factor (A) at same level of B	1.45	NS	NS

value of P and K while narrow spacing of 30 cm × 25 cm exhibited the lowest (23.92 and 203.3 kg ha^{-1}) values. In terms of nutrient management, 50 % N RDF + 50 % N FYM showed the highest (168.46, 26.43, 222.693 kg ha^{-1}) amount of available N, P and K while control exhibited the lowest (143.37, 21.92, 196.306 kgha^{-1}) among all the other treatments.

Interaction between both spacing and nutrient management was found to be non-significant in terms of soil physicochemical properties which is soil organic carbon, bulk density and soil available P and K, while interaction of main and sub plots was found to be significant in terms of available nitrogen and it exhibited maximum (174.17 kg ha^{-1}) values at raised bed sown pigeon pea with 50 % N RDF + 50 % N FYM treatment combination.

Principal component analysis (PCA)

PCA analysis between soil parameters

Fig. 2 shows PC1 (principal component 1) representing soil chemical properties and PC2 (principal component 2) representing soil physical properties. Greater separation between arrows indicates a highly significant difference among parameters, whereas closely spaced arrows indicate a moderate difference. The arrow in the opposing direction indicates a negative correlation between the parameters. Fig. 2 signifies that bulk density is negatively correlated with EC, available N, P, K, pH and OC.

PCA of growth and yield attributes

Fig. 3 shows the PC1 of growth parameters with the PC2 yield parameters. A significant difference was observed between growth and yield attributes. PC1 and PC2 lying on the same side of the axis indicate that increase in growth attributes led to enhance the yield attributes. Between the plant height, primary and secondary branches, chlorophyll index, dry matter accumulation, pod length, pod yield, seed index and seeds per pod very close correlation was found whereas strong positive correlation found with LAI.

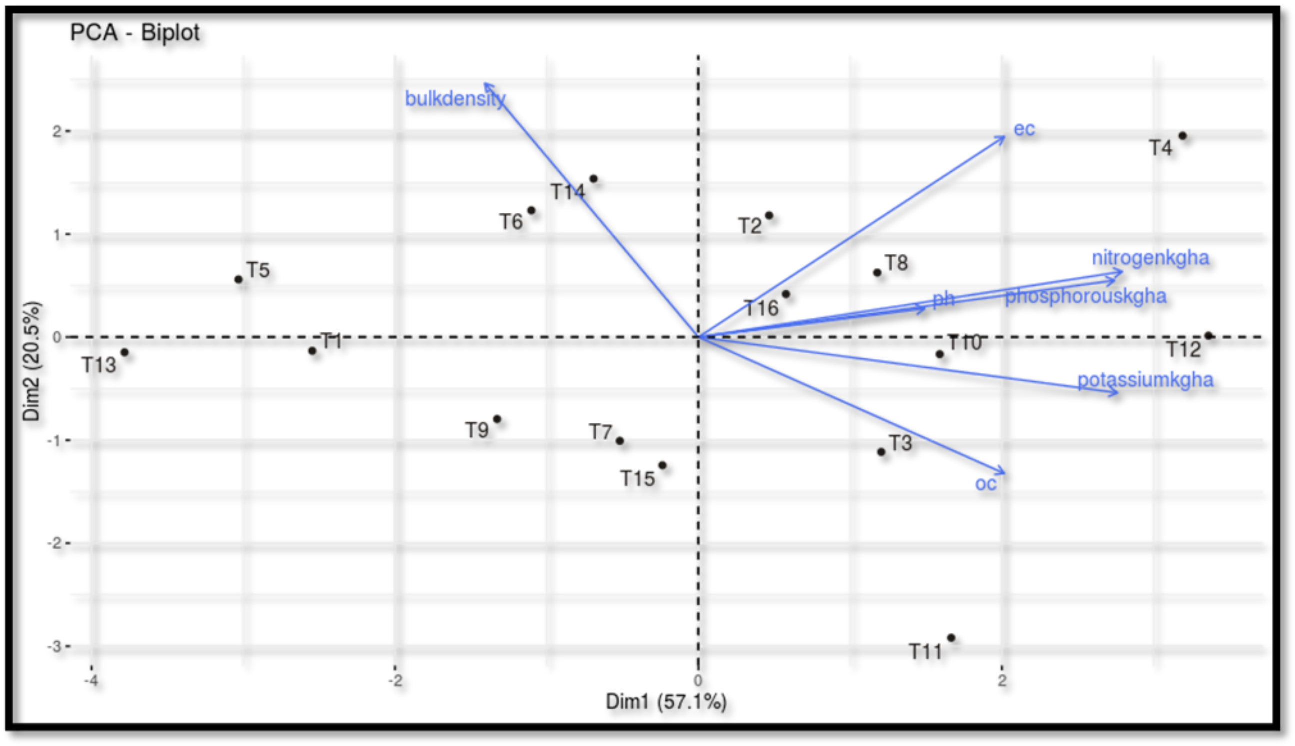

Fig. 2. PCA illustrates the relationship between soil physical and chemical properties.

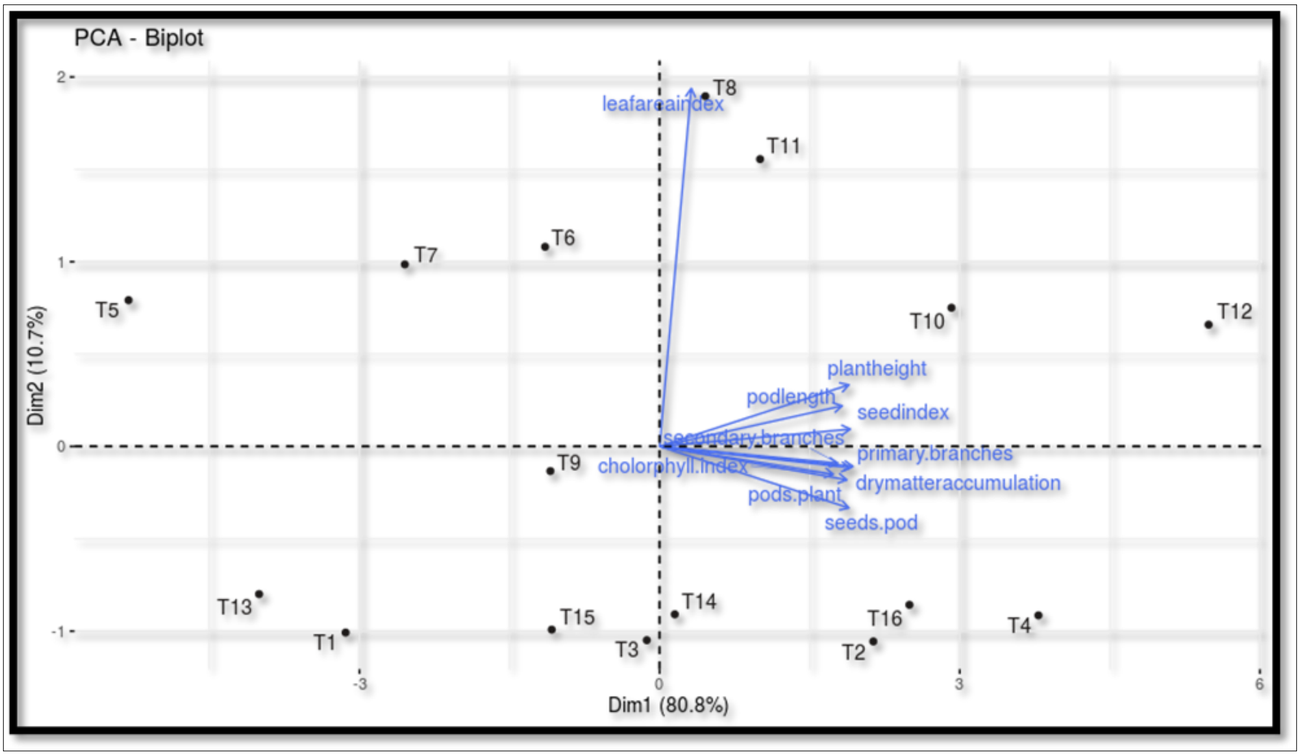

Fig. 3. PCA showing the relationship between the growth and yield parameters of pigeon pea.

PCA of yield and harvest index

Fig. 4 shows PC1 and PC2 of yield with HI. A strong correlation was found between HI and grain, haulm and biological yield. Grain, haulm and biological yield lay on the same scale indicating close relationship among them. On the other hand, the harvest index lay in the same direction, but there was more variation found from the yield. The grain to haulm ratio indicates more accumulation of the photosynthates which is responsible for high biological yield.

Correlation plot of variables vs PCs

Fig. 5 shows the growth parameters and biological yield on the left side of the image whereas the right side of the image represents the correlation values from -1 to +1. Red color indicates negative correlation, light orange indicates moderate correlation and blue represents strong correlation among the variables. The bigger size of the circles indicates strong correlation among different variables, as the decreased size of circles represents negative correlation among various components.

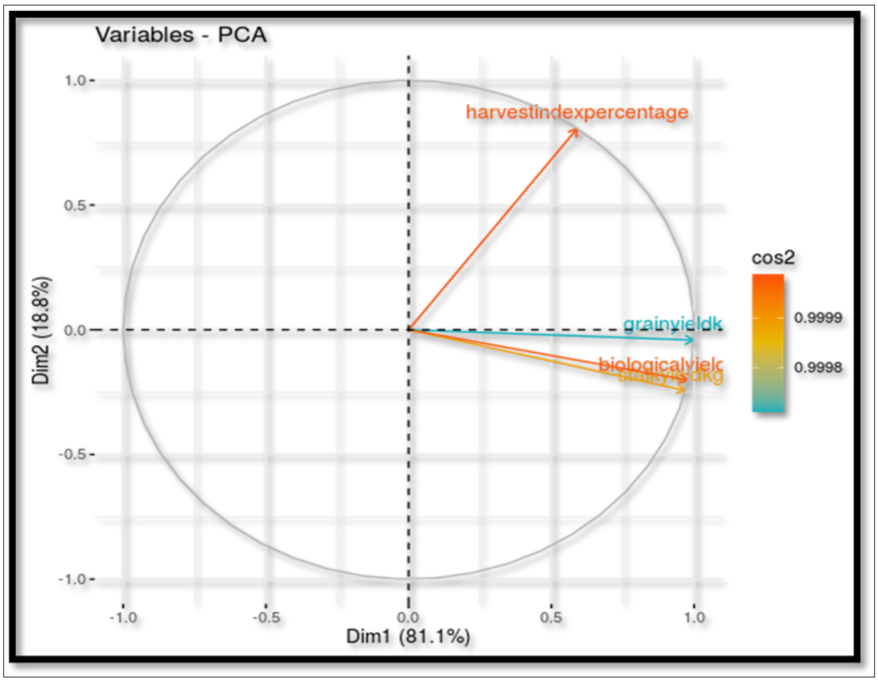

Fig. 4. PCA of harvest index with grain, haulm and biological yield.

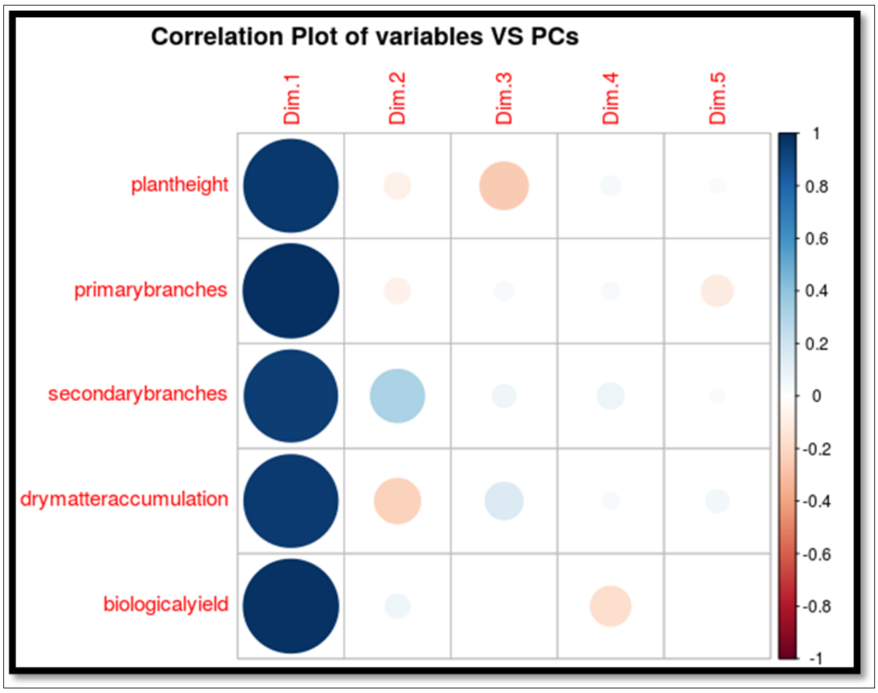

Fig. 5. Correlation between growth attributes with the biological yield.

Discussion

In general, growth and yield parameters were significantly affected by spacing and nutrient management. Raised bed treatment showed significant superiority among growth parameters *viz.* plant height, number of branches and dry matter accumulation while narrow spacings resulted in a higher leaf area index. These results in raised beds might be due to the presence of favorable growing conditions such as seed bed, aeration, better light interception and higher water conservation. Efficient utilization of resources and less competition in wider spaces contrary to the narrow spacing which limits the available resources owing to competition among plants. This result is like the findings of previous studies (12, 13).

The number of branches was more flourished in raised bed that might be due the fact that raised bed provided more available space to the side rows than that of other treatments and greater plant height and vegetative growth of the plants in same treatment. In addition, raised bed planting produced much more dry matter due to a greater number of branches and leaf area plant^{-1} which might have increased the rate of photosynthesis and accumulation of photosynthates in higher quantity during the process of plant metabolism that reflected in dry matter. Among nutrient management practices, a greater number of branches and dry matter were recorded in 50 % N RDF + 50 % N FYM which was significantly superior to other treatments. These results might be due to the combined application of inorganic and organic fertilizers which supply the nutrients throughout the growing period of the crop and enhance their usage efficiency (14). Integrated nutrient management also promote the various physiological activities such as photosynthesis that is considered indispensable to the plant growth and development and further improves the soil health and soil microflora that might have become the cause of higher dry matter in N_4 (50 % N RDF + 50 % N FYM) treatment in comparison to application of either RDF or FYM (15).

LAI showed a gradual increase in the early growing period and started to decline as the crop neared to harvesting maturity. Highest LAI was recorded in narrow spacing of 30 cm × 25 cm, which might be the consequence of increased plant density in narrow spaced treatment. In terms of nutrient management practices 50 % N RDF + 50 % NFYM showed significant superiority among all the treatments and was closely followed by 100 % RDF. This might be the consequence of combined application of organic and inorganic sources which led to the more availability of nutrients and enhanced leaf development and expansion that ultimately led to the increase in leaf output (15, 16).

The increase in number of pods in raised bed might be the consequence of proper crop growth which resulted in better translocation of food material to the reproductive part of the plant that ultimately led to the superiority of yield attributing characters in this treatment. In terms of nutrient management, N_4 i.e. 50 % N RDF + 50 % N FYM showed significantly greater number of pods plant^{-1} which was closely followed by N_2 (100 % RDF). This might be due to the nitrogen fixing nature of pigeon pea along with balanced nutrition provided by integrating organic and inorganic sources that led to the better growth and development resulting in expression of higher values of these yield attributing characters (17).

Raised bed treatments exhibited the highest seed and stalk yield significantly and was closely followed by P_1 (50 cm × 25 cm). Lowest seed and stalk yield were observed in narrower spacing i.e. 30cm × 25cm. This might be due to more favored overall growth and yield attributing characters due to favorable seed bed, better aeration, better light interception leading to increased photosynthetic rate, scope for more space benefit of conserved moisture in furrows and its support at critical growth stages like pod initiation and development. Plant ability to yield seeds is dependent on a variety of factors, including the size, efficiency and duration of their photosynthetic systems as well as the transfer of dry matter into seed. Greater translocation of food materials to the reproductive parts resulted in superiority of yield attributing characters and ultimately highest yield. Higher dry matter production, high growth in terms of LAI resulted in higher production of photosynthates, which acted as a source resulting in higher seed yield (18).

Organic amendments in soil tend to improve the soil physico-chemical properties i.e. bulk density, organic carbon and soil available N, P and K in comparison to their initial status. Soil available N was found to be significantly superior in treatments supplied with combined application of FYM and RDF. This increase might have been due to the mineralization of organic matter which further enhanced the microbial activity, therefore aiding the conversion of organically bound N to mineral form (18). Results indicated that P availability was highest under INM (50 % N RDF + 50 % N FYM). This increase might be the consequence of P solubilization by organic acids released from organic manures joined with decrease of P fixation in soil. Results exhibited that maximum soil available K in N_4 (50 % N RDF + 50 % N FYM), which might be due to the release of organic acids that are produced during the decomposition of organic manures which further reduces the K fixation in soil. Additionally, applying organic manure containing organic acids during the decomposition process might have caused the fixed potassium to mineralize and made K more readily available (19, 20).

According to the results stated above, organic manure (FYM) improved the soil organic carbon content. Though, organic amendments do not have high carbon content in soil significantly. But possibly, slow mineralization of these manures could lead to organic carbon accumulation in soil. Results exhibited a lower value of bulk density with the addition of FYM which might have been the result of increased looseness of soil that further improved the volume of soil means porosity caused by organic fertilizers instead of inorganic fertilizers (21, 22).

Conclusion

It can be concluded from the study that pigeon pea planted on raised bed showed significantly better growth and yield. Also, it performed better when shown at slightly wider spacing (50 cm × 25 cm) rather than narrow spacing which increased the competition for resources among the plants. Whereas application of 50 % N RDF + 50 % N FYM provided better results as compared to either RDF or FYM. Thus, the combined use of organic and inorganic sources not only improved the plant growth and yield but also the balanced application of nutrients improved soil health.

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Authors' contributions

P did field work and wrote the paper. SS did the analysis. AS and ST did the corrections. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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