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Evaluation of Pigeonpea-based Intercropping System for Growth, Productivity, Economics, Available Nutrient and Nutrient Uptake under *Alfisols*

Laxman Navi [a++*], H. M. Atheek ur Rehman [b#], Krishnamurthy, R [c†], S. R. Anand [d‡], Dayanandanaik S [a++] and A. R. Devika [a^]

[a] Department of Agronomy, University of Agricultural Sciences, GKVK, Bengaluru, India.
[b] AICRP on Pigeonpea, ZARS, University of Agricultural Sciences, GKVK, Bengaluru, India.
[c] Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, GKVK, Bengaluru, India.
[d] AICRP on Potential Crops, ZARS, University of Agricultural Sciences, GKVK, Bengaluru, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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[++] *PhD Scholar;*
[#] *Scientist (Agronomy);*
[†] *Associate Professor;*
[‡] *Junior Agronomist;*
[^] *M.Sc. Scholar;*
**Corresponding author: E-mail: navilaxman95@gmail.com;*

ABSTRACT

An experiment was conducted to the evaluation of pigeonpea-based intercropping system for growth, productivity, economics, available nutrient and nutrient uptake under *alfisols* of Karnataka during *Kharif,* 2020 at 'K' Block, Zonal Agricultural Research Station, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra, Bengaluru. The experiment had 15 treatments which were replicated thrice in Randomised Complete Block Design. Treatments consisted of sole crops pigeonpea and different intercrops mixed along with of intercrops (field bean, vegetable soybean and chia) in different row proportions of (1:2, 1:3 and 1:4).The study aimed to assess the growth, yield and economics of pigeonpea comprising planting geometry and different intercrops. The results indicated that the combined effect of paired-row pigeonpea with field bean at 120/60 cm × 30 cm (1:2) spacing recorded the highest seed yield (1770 kg/ha) and stalk yield (4026 kg/ha). Among planting geometry and intercropping systems, higher gross returns, net returns and B:C ratio (Rs. 2,60,591 ha^{-1}, Rs. 2,19,030 ha^{-1} and 6.27 respectively) was recorded in T_7 (paired row pigeonpea with vegetable soybean at 120/60 cm). Among planting geometry and intercropping system highest total nutrient uptake of pigeonpea was recorded in T_6 (Paired row - 120/60 cm × 30 cm pigeonpea + field bean (1:2), 76.65, 12.20 and 98.36 kg/ha NPK respectively) compared to rest of intercropping treatments. In available nutrients, among planting geometry and intercropping systems highest total available nitrogen and phosphorous was recorded in T_{14}: Sole vegetable soybean (318.62 and 107.20 kg/ha N & P respectively) and higher total available potassium was recorded in T_{13}: Sole field bean (321.40 kg/ha K respectively), compared to other treatments. The study concludes that the paired row pigeonpea with vegetable soybean at 120/60 cm x 30 cm yield and economics of the intercropping systems.

Keywords: Pigeonpea; planting geometry; nutrient uptake; available nutrients; pigeonpea equivalent yield.

1. INTRODUCTION

The main objective of intercropping is to improve the productivity of a given unit of land area within a specified timeframe while making efficient and balanced use of land resource, farm inputs (including labor) and without reducing the yield of the base crop [1]. This farming practice involves growing two or more crops together in the same field at same time. It capitalizes on the differences in resource requirements and competitive abilities of the main and component crops. Intercropping can lead to the enhanced efficient utilization of available basic/essential resources such as light, water, and nutrients. This, in turn, can increase resource use efficiency and overall crop yield, benefiting both the farmer and the ecosystem [2]. Inter-row space in pigeonpea during the initial slow growth period provides ample scope to cultivate the compatible crops in between two rows of pigeonpea and increase the productivity per unit area and time because of its wider row spacing and plasticity of the crop to row spacing which helps for better utilization of the resources like nutrients for higher yield. The demand for pulses in India is observed due to lesser area under pulses and lower productivity. To meet the demand, pulse production has to be increased. Pigeonpea, a prominent *Kharif* pulse crop especially in dryland farming and is commonly grown in large area as intercrop with other cereal crops rather than sole crop. Higher productivity per unit time and space, and higher net returns is possible with intercropping systems over monoculture, legume-based intercropping systems are thought to be superior for securing higher pulse crop yield. Pigeonpea based cropping system address the nitrogen economy and yield because of their different rooting habits, differential growth, demand for resources and complementary interactions brought about by nitrogen fixation by legumes since legumes add enormous organic biomass (leaf, nodules, roots etc). Nutrient management plays an important role, especially in intercropping syatems. The yield of both main and intercrops depends on availability of nutrient and further persistence of nutrients after harvest of the crops is necessary for succeeding crop. In this sense pulse base inter cropping system by replenishing soil with nutrient play a vital role in sustainability of agriculture ecosystem. Kumawat et al. [3] found that normal and paired row intercropping system gave significantly higher uptake of N, P and K when compared to sole pigeonpea. The available soil N, P, K after harvest of crop was maximum observed under sole pigeonpea followed by normal intercropping and lowest in paired intercropping. And efforts have been made to identify suitable intercropping in pigeonpea for various agro-climatic zones of Karnataka.

2. MATERIALS AND METHODS

2.1 Experimental Site and Soil

A field experiment was conducted during *Kharif,* 2020 at ‘K’ Block, Zonal Agricultural Research Station, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra, Bengaluru to study the evaluation of pigeonpea-based intercropping system for growth, productivity, economics, available nutrient and nutrient uptake under *alfisols* Karnataka and Located between 12º 51' N Latitude and 77º 35' E Longitude at an altitude of 930 m above mean sea level (MSL). The soil of the experimental site was red sandy loam in texture, classified under the order *Alfisols*. The soil was acidic (5.03) in reaction with an electrical conductivity of 0.12 dS m^{-1}. The organic carbon content was 0.46 per cent. The soil was medium in available nitrogen (312.5 kg ha^{-1}), available phosphorous (28.5 kg ha^{-1}) and available potassium (295.0 kg ha^{-1}).

2.2 Design of Experiment and Treatment Details

The experiment consisted of 15 treatments which were replicated thrice in Randomised Complete Block Design. Treatments consisted of various combinations of planting geometry and intercropping. In pigeonpea crop the treatments are tried as follows, T_1: Normal row (120 cm x 30 cm) Pigeonpea (Sole crop), T_2: Normal row (120 cm x 30 cm) Pigeonpea + Field bean (1:2), T_3: Normal row (120 cm x 30 cm) Pigeonpea + Vegetable soybean (1:3), T_4: Normal row (120 cm x 30 cm) Pigeonpea + Chia (1:2), T_5: Paired row (120/60 cm x 30 cm) Pigeonpea (Sole crop), T_6: Paired row (120/60 cm x 30 cm) Pigeonpea + Field bean (1:2), T_7: Paired row (120/60 cm x 30 cm) Pigeonpea + Vegetable Soybean (1:3), T_8: Paired row (120/60 cm x 30 cm) Pigeonpea + Chia (1:2), T_9: Paired row (150/60 cm x 45 cm) Pigeonpea (Sole crop), T_{10}: Paired row (150/60 cm x 45 cm) Pigeonpea + Field bean (1:3), T_{11}: Paired row (150/60 cm x 45 cm) Pigeonpea + Vegetable Soybean (1:4), T_{12}: Paired row (150/60 cm x 45 cm) Pigeonpea + Chia (1:3), T_{13}: Field bean (Sole crop – 45 cm x 15 cm), T_{14}: Vegetable Soybean (Sole crop – 30 cm x 10 cm) and T_{15}: Chia (Sole crop – 45 cm x 15 cm).

After harvest of the previous crop, the land was ploughed with tractor drawn disc plough and harrowed twice to crush the clods and make the soil loose and friable. Farm yard manure was applied at the time of harrowing for uniform mixing with soil at 2-3 weeks before sowing of the crop. Stubbles, roots and weeds were removed from the experimental area. Later, rotovator was passed to bring the soil to fine tilth. Pigeonpea variety (BRG-4), vegetable soybean (Karune), field bean (HA-4) and Chia (GKVK chia-1) recommended by UASB were used. Pigeonpea crop sown in paired row/normal row as per the treatments. The intercrops are sown at prescribed spacing fieldbean (45 cm x 15 cm), vegetable soybean (30 cm x 10 cm) and chia (45 cm x 15 cm) in between the pigeonpea at different row proportion as per the treatments at their recommended seed rate 15 kg ha^{-1}, 30 kg ha^{-1}, 62.5 kg ha^{-1} and 2 kg ha^{-1}, respectively during first fortnight of July, 2020.

Farm yard manure was applied at the rate of 8 tonnes/ha to each plot three weeks prior to sowing. Recommended dose of nutrients were applied for the sole pigeonpea (25: 50: 25 kg N, P_2O_5 and K_2O ha^{-1}, respectively), field bean (25: 50: 25 kg N, P_2O_5 and K_2O ha^{-1}, respectively) soybean (25: 62: 25 kg N, P_2O_5 and K_2O ha^{-1}, respectively) and chia (100: 50: 50 kg N, P_2O_5 and K_2O ha^{-1}, respectively) using urea, di-ammonium phosphate and muriate of potash fertilizers. In the intercropping system, the nutrients were applied based on recommended full dose of the main crop and the half-recommended dose of the nutrients of component under intercropping. The entire quantities of nutrients were applied to both the main crops and component crops at the time of sowing as basal dosage as per UASB package of practice.

Two hand weedings (20 DAS and 40 DAS) were carried out at critical stages of crop weed competition. First hand weeding was done at 20 days after sowing to keep plots free from weeds. Second hand weeding was done at 40 days after sowing followed by intercultivation and earthing up operation.

The soil from each treatment were drawn after harvest of the crop and analysed for available nitrogen, phosphorus and potassium. And was determined by alkaline permanganate method as outlined by Subbiah and Asija [4], Olsen’s method using spectrophotometer and neutral normal ammonium acetate extractant using flame photometer as outlined by Jackson [5], respectively.

The plant from each treatment were collected, processed and used for nutrient uptake analysis. Nitrogen content was estimated by modified Micro-Kjeldhal's method as outlined by Jackson [5] and expressed in percentage. Nitrogen uptake (kg ha^{-1}) by crop was calculated using the following formula.

$$\text{Nitrogen uptake (kg ha}^{-1}) = \frac{\text{Nitrogen concentration (\%) x Biomass (kg ha}^{-1})}{100}$$

Phosphorus content of the digested plant sample was estimated by Vanadomolybdate phosphoric yellow colour method in nitric acid medium and the colour intensity was measured at 660 nm wave length as outlined by Jackson [5]. It is calculated using the following formula.

$$\text{Phosphorus uptake (kg ha}^{-1}) = \frac{\text{Phosphorus concentration (\%) x Biomass (kg ha}^{-1})}{100}$$

Potassium content of digested plant samples was estimated by atomizing the diluted acid extract in a flame photometer as described by Jackson [5]. It is calculated using the following formula.

$$\text{Potassium uptake (kg ha}^{-1}) = \frac{\text{Potassium concentration (\%) x Biomass (kg ha}^{-1})}{100}$$

2.3 Statistical Analysis

The soil and plant analysed data were subjected to Fisher's method of "Analysis of Variance" (ANOVA) as outlined by Panse and Sukhatme [6]. The analysis and interpretation of data were done. The level of significance used in "F" and "t" test was p=0.05, Critical difference values were calculated when the "F" test was significant.

3. RESULTS AND DISCUSSION

3.1 Dry Matter Accumulation (g $plant^{-1}$)

The data pertaining to dry matter accumulation by pigeonpea as influenced by different planting geometry and intercropping system of pigeonpea are presented in Table 1. Among different planting geometry, sole paired row pigeonpea at 120/60 cm spacing recorded significantly higher dry matter accumulation (25.2, 87.1, 135.2 and 166.3 g $plant^{-1}$ respectively) at 45, 90, 135 DAS and at harvest, whereas lower dry matter accumulation (15.5, 61.2, 94.5 and 108.3 g $plant^{-1}$ respectively) at 45, 90, 135 DAS and at harvest was observed in pigeonpea + chia at (1:2) intercropping under normal row planting.

The higher dry matter accumulation was found with 120/60 cm × 30 cm paired row planting of pigeonpea as the plant population of pigeonpea were higher than sole cropping at 120 cm × 30 cm. The treatments recorded higher biomass accumulation as there was no competition for resources with intercrops. Pigeonpea intercropped with soybean with 120 cm × 30 cm paired planting may be due to better weed control and there was no much competition between these two crops as both fix their own nitrogen and extract soil moisture from different depths. The results are in confirmity with findings [7,8,9].

3.2 Growth Rate of Pigeonpea

3.2.1 Absolute growth rate (g day^{-1})

It was evident from the data presented in Table 2 that absolute growth rate (g day^{-1}) was significantly affected by different planting geometry and intercropping. During crop growth stages of 0-45, 45-90 and 90-135 DAS, the planting geometry and intercropping system of paired row (120/60 cm × 30 cm) of sole pigeonpea recorded significantly higher absolute growth rate (0.560, 1.375 and 1.069 g day^{-1}, respectively), where as in normal row (120 cm × 30 cm) of pigeonpea + chia (1:2) recorded lower absolute growth rate (0.344, 1.016 and 0.739 g day^{-1}, respectively).

3.2.2 Crop growth rate (g m^{-2} day^{-1})

It was evident from the data presented in Table 3 that crop growth rate (g m^{-2} day^{-1}) was significantly affected by different planting geometry and intercropping system. During crop growth stages of 0-45, 45-90 and 90-135 DAS, the planting geometry and intercropping of paired row (120/60 cm × 30 cm) of sole pigeonpea recorded significantly higher crop growth rate (2.07, 5.09 and 3.95 g m-2 day^{-1}, respectively), where as in normal row (120 cm × 30 cm) of pigeonpea + chia (1:2) recorded lower crop growth rate (0.95, 2.81 and 2.05 g m-2 day^{-1}, respectively).

3.2.3 Relative growth rate (g g^{-1} day^{-1})

There was no significant difference between the treatments for relative growth rate during crop growth stages of 0-45, 45-90 and 90-135 DAS, the planting geometry and intercropping system of paired row (120/60 cm × 30 cm) sole pigeonpea recorded higher relative growth rate (0.072, 0.028 and 0.001 g g-1 day^{-1}), where as in normal row (120 cm × 30 cm) of pigeonpea + chia (1:2) recorded lower relative growth rate (0.061, 0.031 and 0.001g g^{-1} day^{-1}) during 0-45, 45-90 and 90-135 DAS respectively and data are presented in Table 4.

The higher growth rate of pigeonpea in the treatment sole pigeonpea under 120/60 cm × 30 cm paired row might be due to higher interception of solar radiation, low competition for resources as the crop was weed free. The next best treatment, vegetable soybean intercropping under 120/60 cm × 30 cm paired row might be due the both the crops has different feeding zones and critical stages might not have overlapped indicating the combination of planting geometry and choice of intercrop match in terms of efficient resource utilization. The similar results were by [10,11,12].

3.3 Yield of Pigeonpea and Component Crops

Seed and stalk yield of pigeonpea were favourably influenced by pigeonpea-based intercropping system (Table 5 and Fig. 1). Among different planting geometry, significantly higher seed yield (1813 kg ha^{-1}) was observed in paired row (120/60 cm × 30 cm) of sole pigeonpea and was on par with T_6 (1770 kg ha^{-1}) and T_7 (1699 kg ha^{-1}), whereas lowest seed yield (768 kg ha^{-1}) was observed in normal row (120 cm × 30 cm) of pigeonpea + chia (1:2). Significantly higher stalk yield (4218 kg ha^{-1}) was observed in paired row (120/60 cm × 30 cm) of sole pigeonpea. The treatments T_6 (4026 kg ha^{-1}) and T_7 (3981 kg ha^{-1}) were on par with T_5. Lower stalk yield (2597 kg ha^{-1}) was observed in normal row (120 cm × 30 cm) of pigeonpea + chia (1:2). In pigeonpea equivalent yield, among different intercropping system paired row pigeonpea with vegetable soybean at 120/60 cm spacing recorded significantly higher pigeonpea equivalent yield (1843 kg ha^{-1}) and was being on par with paired row pigeonpea with field bean at 120/60 cm spacing (1842 kg ha^{-1}) and Lower PEY was recorded in normal row pigeonpea + field bean 1:2 row proportion (1363 kg ha^{-1}).

The higher pigeonpea crop yield is due to competition free environment for pigeonpea under sole cropping. Further the pigeonpea yield was higher under paired row could be indicating that the micro climate suitable for pigeonpea is found unerd paired row than existing normal row planting geometry. Further, intercropping with field bean and vegetable soybean which recorded on par yield as compared with sole pigeonpea demonstrated that these low growing, short duration pulses were does not interfere much with growth of pigeonpea and it has near similar sole crop conditions. Where we see overall production from the system and it is much more productive than the sole crop. This clearly illustrate that field bean and vegetable soybean are better option as component crops under intercropping system was also reported by by Yamuna [13], Kavya et al. [14] and Kumar et al. [15,16].

This may be attributed to enhanced growth, increased yield attributes, and improved nutrient uptake, coupled with more efficient utilization of available resources. The inclusion of fieldbean in the paired row system likely exerted a stronger synergistic effect, leading to comparable yields in the pigeonpea crop associated with fieldbean and vegetable soybean in the paired row system. This outcome is likely due to their staggered maturation times, contributing to a more effective utilization of both space and time. The arrangement of rows, as opposed to the placement of individual crops within rows, may also impact the productivity of the intercropping system.

The primary factor contributing to higher yields in intercropping systems is likely the introduction of nitrogen into the soil through biological nitrogen fixation (BNF), coupled with the more effective utilization of available growth resources such as water, nutrients, light, and air. Additionally, the optimized use of the land parcel and the interactions and facilitation among the component crops play a crucial role in achieving greater productivity. Similar positive effects of planting geometry and intercropping arrangements are observed, emphasizing the complementary nature of these factors was also reported by Turkhede et al. [17], Rekha and Dhurua [18], Narendra et al. [19] and Kasbe et al. [20].

3.4 Economics of Pigeonpea and Component Crops

The data pertaining to economics (gross returns, net returns and C:B ratio) by different intercrops as influenced by different planting geometry and intercropping system of pigeonpea are presented in Table 6 and Fig. 2. In gross returns, higher gross returns (Rs. 2,60,591 ha^{-1}) recorded in T_7 (paired row pigeonpea with vegetable soybean at 120/60 cm), whereas lower gross returns (Rs. 74,506 ha^{-1}) were recorded in T_{13} (sole field bean). In net returns, higher net returns (Rs. 2,19,030 ha^{-1}) were recorded in T_7 (paired row pigeonpea with vegetable soybean at 120/60 cm), whereas lower gross returns (Rs. 41,263 ha^{-1}) were recorded in T_1 (normal row sole pigeonpea). Among different intercrops tried, higher C: B ratio (6.27) was recorded in T_7 (paired row pigeonpea with vegetable soybean at 120/60 cm), whereas lowest C:B ratio (2.09) was observed in T_4 (normal row pigeonpea with chia crop at 1:2 ratio). In sole crop of different intercrops tried the vegetable soybean recorded highest returns per rupee invested (C:B ratio, 6.94) compared to other sole crops field bean and chia with C:B ratio of 2.88 and 2.61, respectively.

Ultimately economics is the deciding factor acceptance of any technology by its end user, the farmer. In the study the inter cropping of vegetable soybean with pigeonpea under wider paired row system 120/60 cm × 30 cm followed by 150/60 cm × 45 cm recorded the higher net returns as well as cost - benefit ration due to higher system yield as well as better price of both main and component crops prevailing in the market [21,22,15,16].

3.5 Available Soil Nutrient Status

The data on soil available nutrients presented in Table 7 and depicted Fig. 3, revealed that maximum available nutrients *viz.,* Numerically, higher available nitrogen (318.62 kg ha^{-1}) and significantly higher available phosphorous (107.20 kg ha^{-1}) was observed in sole vegetable soybean. While significantly higher available potassium (321.40 kg ha^{-1}) was observed in sole field bean. The lower available nitrogen (280.99 kg ha^{-1}), phosphorous (58.40 kg ha^{-1}) and potassium (217.36 kg ha^{-1}) was observed in sole pigeonpea under paired row at 120/60 cm spacing.

3.6 Nutrient Uptake by the Pigeonpea

The data on plant nutrient uptake presented in Table 8, among different planting geometry sole paired row pigeonpea at 120/60 cm spacing recorded significantly higher nitrogen, phosphorous and potassium uptake (82.48, 12.60 and 102.80 kg ha^{-1} respectively). Whereas lower nitrogen phosphorous and potassium uptake (57.45, 7.86 and 74.12 kg ha^{-1} respectively) was observed in pigeonpea + chia at (1:2) intercropping under normal row planting. Among different intercropping system pigeonpea + field bean (1:2) recorded significantly higher nitrogen, phosphorous and potassium uptake (76.65, 12.20 and 98.36 kg ha^{-1} respectively) under paired row planting (120/60 cm × 30 cm) as compared to other treatments.

3.7 Nutrient Uptake by the Intercrops

The data pertaining to nutrient uptake (nitrogen, phosphorus and potassium) by different intercrops as influenced by different planting geometry and intercropping system of pigeonpea at the time of harvest are presented in Table 8. The treatment, sole chia crop recorded numerically higher nitrogen and potassium uptake (105.48 and 96.48 kg ha^{-1} respectively) and The treatment sole field bean crop recorded numerically higher phosphorous uptake (41.00 kg ha^{-1}). Whereas, lower nitrogen, phosphorous and potassium uptake (37.58, 16.80 and 28.42 kg ha^{-1}) recorded in normal row pigeonpea + vegetable soybean at 1:3 row ratio. This indicates that pulse as intercrop in pulse crop helps in sustaining soil fertility by replenishing with nutrients.

The higher nutrient uptake and lower soil available nutrients were recorded with sole crop of pigeonpea under 120/60 cm × 30 cm might be due to higher plant population and also no beneficial effect by component crops. The results are in confimity with findings of Kumawat *et al.* [3], Nagar et al. [23] and Sekhon et al. [24]. Whereas higher build-up of organic carbon and residual available nutrients were more with sole pigeonpea / field bean as well as with intercropping. The similar trend was also observed by Turkhede et al. [17]. The incorporation of legumes in intercropping systems appears to stimulate a diverse array of rhizosphere microbes, facilitating the mobilization of inherent phosphorus (P) and potassium (K) as well as other nutrients. This phenomenon results in increased availability and uptake of these nutrients by plants. Additionally, the introduction of organic matter in the form of leaf litter from leguminous components further contributes to this nutrient enhancement. Utilizing high-quality plant residues ensures a timely release of nutrients, promoting enhanced uptake by crops.

Legumes, known for producing superior quality residues, present a cost-effective opportunity for sustaining soil fertility. Their contribution to nutrient release during decomposition, as indicated by Baijukya [25], plays a crucial role in improving soil organic matter and enhancing soil physical properties. In this way, intercropping with legumes proves to be a valuable strategy for maintaining soil fertility and supporting optimal crop growth [26]. Chia, being non leguminous and exhaustive crop, soil available nutrients and other parameters were low after the crop harvest [27].

Table 1. Dry matter accumulation (g plant^{-1}) of pigeonpea at different growth stages as influenced by planting geometry and intercrops in pigeonpea based cropping system

Treatments		45 DAS	90 DAS	135 DAS	At harvest
T_1:	NR (120 cm × 30 cm) Pigeonpea (Sole crop)	19.9	68.2	104.4	134.1
T_2:	NR (120 cm × 30 cm) Pigeonpea + Field bean (1:2)	18.0	65.2	100.5	130.1
T_3:	NR (120 cm × 30 cm) Pigeonpea + Vegetable soybean (1:3)	19.2	66.3	102.3	132.2
T_4:	NR (120 cm × 30 cm) Pigeonpea + Chia (1:2)	15.5	61.2	94.5	108.3
T_5:	PR (120/60 cm × 30 cm) Pigeonpea (Sole crop)	25.2	87.1	135.2	166.3
T_6:	PR (120/60 cm × 30 cm) Pigeonpea + Field bean (1:2)	23.5	82.5	128.7	160.1
T_7:	PR (120/60 cm × 30 cm) Pigeonpea + Vegetable Soybean (1:3)	24.1	84.3	131.3	163.5
T_8:	PR (120/60 cm × 30 cm) Pigeonpea + Chia (1:2)	17.3	63.9	98.8	125.1
T_9:	PR (150/60 cm × 45 cm) Pigeonpea (Sole crop)	21.2	72.6	108.9	137.6
T_{10}:	PR (150/60 cm × 45 cm) Pigeonpea + Field bean (1:3)	19.7	66.2	103.5	132.0
T_{11}:	PR (150/60 cm × 45 cm) Pigeonpea + Vegetable Soybean (1:4)	20.3	69.4	106.7	135.3
T_{12}:	PR (150/60 cm × 45 cm) Pigeonpea + Chia (1:3)	16.3	62.1	96.5	120.4
S.Em.±		0.52	2.07	3.55	5.43
CD (5%)		1.53	6.07	10.43	15.91

Note: DAS: Days After Sowing, NR: Normal row, PR: Paired row

Table 2. Absolute growth rate (g day^{-1}) of pigeonpea at different growth stages as influenced by planting geometry and intercrops in pigeonpea based cropping system

Treatments		0-45 DAS	45-90 DAS	90-135 DAS
T_1:	NR (120 cm × 30 cm) Pigeonpea (Sole crop)	0.441	1.074	0.805
T_2:	NR (120 cm × 30 cm) Pigeonpea + Field bean (1:2)	0.400	1.049	0.785
T_3:	NR (120 cm × 30 cm) Pigeonpea + Vegetable soybean (1:3)	0.427	1.045	0.802
T_4:	NR (120 cm × 30 cm) Pigeonpea + Chia (1:2)	0.344	1.016	0.739
T_5:	PR (120/60 cm × 30 cm) Pigeonpea (Sole crop)	0.560	1.375	1.069
T_6:	PR (120/60 cm × 30 cm) Pigeonpea + Field bean (1:2)	0.521	1.312	1.026
T_7:	PR (120/60 cm × 30 cm) Pigeonpea + Vegetable Soybean (1:3)	0.536	1.336	1.044
T_8:	PR (120/60 cm × 30 cm) Pigeonpea + Chia (1:2)	0.384	1.037	0.775
T_9:	PR (150/60 cm × 45 cm) Pigeonpea (Sole crop)	0.470	1.142	0.806
T_{10}:	PR (150/60 cm × 45 cm) Pigeonpea + Field bean (1:3)	0.437	1.034	0.830
T_{11}:	PR (150/60 cm × 45 cm) Pigeonpea + Vegetable Soybean (1:4)	0.451	1.092	0.828
T_{12}:	PR (150/60 cm × 45 cm) Pigeonpea + Chia (1:3)	0.362	1.019	0.763
S.Em.±		0.015	0.039	0.029
CD (5%)		0.044	0.113	0.086

Note: DAS: Days After Sowing, NR: Normal row, PR: Paired row

Table 3. Crop growth rate (g m^{-2} day^{-1}) of pigeonpea at different growth stages as influenced by planting geometry and intercrops in pigeonpea based cropping system

Treatments		0-45 DAS	45-90 DAS	90-135 DAS
T_1:	NR (120 cm × 30 cm) Pigeonpea (Sole crop)	1.22	2.98	2.23
T_2:	NR (120 cm × 30 cm) Pigeonpea + Field bean (1:2)	1.11	2.91	2.17
T_3:	NR (120 cm × 30 cm) Pigeonpea + Vegetable soybean (1:3)	1.18	2.90	2.22
T_4:	NR (120 cm × 30 cm) Pigeonpea + Chia (1:2)	0.95	2.81	2.05
T_5:	PR (120/60 cm × 30 cm) Pigeonpea (Sole crop)	2.07	5.09	3.95
T_6:	PR (120/60 cm × 30 cm) Pigeonpea + Field bean (1:2)	1.93	4.86	3.80
T_7:	PR (120/60 cm × 30 cm) Pigeonpea + Vegetable Soybean (1:3)	1.98	4.94	3.86
T_8:	PR (120/60 cm × 30 cm) Pigeonpea + Chia (1:2)	1.42	3.84	2.87
T_9:	PR (150/60 cm × 45 cm) Pigeonpea (Sole crop)	1.49	3.62	2.56
T_{10}:	PR (150/60 cm × 45 cm) Pigeonpea + Field bean (1:3)	1.39	3.28	2.63
T_{11}:	PR (150/60 cm × 45 cm) Pigeonpea + Vegetable Soybean (1:4)	1.43	3.46	2.63
T_{12}:	PR (150/60 cm × 45 cm) Pigeonpea + Chia (1:3)	1.15	3.23	2.42
S.Em.±		0.05	0.12	0.09
CD (5%)		0.14	0.36	0.28

Note: DAS: Days After Sowing, NR: Normal row, PR: Paired row

Table 4. Relative growth rate (g g^{-1} day^{-1}) of pigeonpea at different growth stages as influenced by planting geometry and intercrops in pigeonpea based cropping system

Treatments		**0-45 DAS**	**45-90 DAS**	**90-135 DAS**
T_1:	NR (120 cm × 30 cm) Pigeonpea (Sole crop)	0.066	0.027	0.009
T_2:	NR (120 cm × 30 cm) Pigeonpea + Field bean (1:2)	0.064	0.029	0.001
T_3:	NR (120 cm × 30 cm) Pigeonpea + Vegetable soybean (1:3)	0.066	0.028	0.001
T_4:	NR (120 cm × 30 cm) Pigeonpea + Chia (1:2)	0.061	0.031	0.001
T_5:	PR (120/60 cm × 30 cm) Pigeonpea (Sole crop)	0.072	0.028	0.001
T_6:	PR (120/60 cm × 30 cm) Pigeonpea + Field bean (1:2)	0.070	0.028	0.001
T_7:	PR (120/60 cm × 30 cm) Pigeonpea + Vegetable Soybean (1:3)	0.071	0.028	0.001
T_8:	PR (120/60 cm × 30 cm) Pigeonpea + Chia (1:2)	0.063	0.029	0.001
T_9:	PR (150/60 cm × 45 cm) Pigeonpea (Sole crop)	0.068	0.027	0.009
T_{10}:	PR (150/60 cm × 45 cm) Pigeonpea + Field bean (1:3)	0.066	0.027	0.001
T_{11}:	PR (150/60 cm × 45 cm) Pigeonpea + Vegetable Soybean (1:4)	0.067	0.027	0.001
T_{12}:	PR (150/60 cm × 45 cm) Pigeonpea + Chia (1:3)	0.062	0.030	0.001
S.Em.±		0.002	0.001	0.0003
CD (5%)		NS	NS	NS

Note: *DAS: Days After Sowing, NR: Normal row, PR: Paired row, NS: Non Significant*

Table 5. Yield of pigeonpea and component crops as influenced by planting geometry and intercrops in pigeonpea-based intercropping system

Treatments	Pigeonpea seed yield (kg ha^{-1})	Pigeonpea stalk yield (kg ha^{-1})	Intercrop seed yield (kg ha^{-1})	Intercrop stalk yield (kg ha^{-1})	PEY (kg ha^{-1})
T_1: NR (120 cm × 30 cm) Pigeonpea (Sole crop)	1264	2954	-	-	1264
T_2: NR (120 cm × 30 cm) Pigeonpea + Field bean (1:2)	1293	3054	210	1012	1363
T_3: NR (120 cm × 30 cm) Pigeonpea + Vegetable soybean (1:3)	1312	3218	389	690	1441
T_4: NR (120 cm × 30 cm) Pigeonpea + Chia (1:2)	768	2597	285	1113	1483
T_5: PR (120/60 cm × 30 cm) Pigeonpea (Sole crop)	1813	4218	-	-	1813
T_6: PR (120/60 cm × 30 cm) Pigeonpea + Field bean (1:2)	1770	4026	216	1296	1842
T_7: PR (120/60 cm × 30 cm) Pigeonpea + Vegetable Soybean (1:3)	1699	3981	433	832	1843
T_8: PR (120/60 cm × 30 cm) Pigeonpea + Chia (1:2)	1099	2868	293	1288	1833
T_9: PR (150/60 cm × 45 cm) Pigeonpea (Sole crop)	1548	3615	-	-	1547
T_{10}: PR (150/60 cm × 45 cm) Pigeonpea + Field bean (1:3)	1479	3460	296	1342	1584
T_{11}: PR (150/60 cm × 45 cm) Pigeonpea + Vegetable Soybean (1:4)	1455	3341	485	859	1650
T_{12}: PR (150/60 cm × 45 cm) Pigeonpea + Chia (1:3)	937	2705	332	1408	1769
T_{13}: Field bean (Sole crop- 45 cm × 15 cm)	-	-	1120	2043	1423
T_{14}: Vegetable soybean (Sole crop – 30 cm × 10 cm)	-	-	775	1387	1522
T_{15}: Chia (Sole crop – 45 cm × 15 cm)	-	-	548	2677	2636
S.Em.±	46.24	104.28	NA	NA	59.299
CD (5%)	**135.63**	**305.85**	**-**	**-**	**171.782**

Note: *NR: Normal row, PR: Paired row, NA: Not analysed, PEY: Pigeonpea equivalent yield*

Table 6. Economics of pigeonpea equivalent yield as influenced by spacing and intercrops in pigeonpea based paired row cropping system

Treatment		Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	C:B ratio
T_1:	NR (120 cm × 30 cm) Pigeonpea (Sole crop)	35,995	77,257	41,263	2.15
T_2:	NR (120 cm × 30 cm) Pigeonpea + Field bean (1:2)	40,949	1,19,837	78,888	2.93
T_3:	NR (120 cm × 30 cm) Pigeonpea + Vegetable soybean (1:3)	41,560	2,11,069	1,69,509	5.08
T_4:	NR (120 cm × 30 cm) Pigeonpea + Chia (1:2)	43,123	90,188	47,065	2.09
T_5:	PR (120/60 cm × 30 cm) Pigeonpea (Sole crop)	35,995	1,14,369	78,375	3.18
T_6:	PR (120/60 cm × 30 cm) Pigeonpea + Field bean (1:2)	40,949	1,25,297	84,348	3.06
T_7:	PR (120/60 cm × 30 cm) Pigeonpea + Vegetable Soybean (1:3)	41,560	2,60,591	2,19,030	6.27
T_8:	PR (120/60 cm × 30 cm) Pigeonpea + Chia (1:2)	43,123	1,11,374	68,251	2.58
T_9:	PR (150/60 cm × 45 cm) Pigeonpea (Sole crop)	35,995	94,628	58,633	2.63
T_{10}:	PR (150/60 cm × 45 cm) Pigeonpea + Field bean (1:3)	41,019	1,48,230	1,07,211	3.61
T_{11}:	PR (150/60 cm × 45 cm) Pigeonpea + Vegetable Soybean (1:4)	41,630	2,59,851	2,18,220	6.24
T_{12}:	PR (150/60 cm × 45 cm) Pigeonpea + Chia (1:3)	43,173	1,07,512	64,339	2.49
T_{13}:	Field bean (Sole crop- 45 cm × 15 cm)	25,863	74,506	48,644	2.88
T_{14}:	Vegetable soybean (Sole crop – 30 cm × 10 cm)	27,055	1,87,897	1,60,841	6.94
T_{15}:	Chia (Sole crop – 45 cm × 15 cm)	31,571	82,321	50,749	2.61

Note: *NR: Normal row, PR: Paired row*

Table 7. Available nitrogen, phosphorous and potassium content in soil after harvest of crop as influenced by planting geometry and intercrops in pigeonpea based cropping system

Treatment		N (kg ha^{-1})	P_2O_5 (kg ha^{-1}	K_2O (kg ha^{-1})
T_1:	NR (120 cm × 30 cm) Pigeonpea (Sole crop)	307.33	61.70	262.36
T_2:	NR (120 cm × 30 cm) Pigeonpea + Field bean (1:2)	286.00	64.50	238.24
T_3:	NR (120 cm × 30 cm) Pigeonpea + Vegetable soybean (1:3)	289.77	68.35	240.56
T_4:	NR (120 cm × 30 cm) Pigeonpea + Chia (1:2)	283.49	61.60	230.12
T_5:	PR (120/60 cm × 30 cm) Pigeonpea (Sole crop)	280.99	58.40	217.36
T_6:	PR (120/60 cm × 30 cm) Pigeonpea + Field bean (1:2)	286.00	59.50	221.65
T_7:	PR (120/60 cm × 30 cm) Pigeonpea + Vegetable Soybean (1:3)	283.49	69.40	227.34
T_8:	PR (120/60 cm × 30 cm) Pigeonpea + Chia (1:2)	289.77	60.60	226.24
T_9:	PR (150/60 cm × 45 cm) Pigeonpea (Sole crop)	296.04	70.90	244.74
T_{10}:	PR (150/60 cm × 45 cm) Pigeonpea + Field bean (1:3)	293.53	62.20	223.12
T_{11}:	PR (150/60 cm × 45 cm) Pigeonpea + Vegetable Soybean (1:4)	298.55	77.40	230.56
T_{12}:	PR (150/60 cm × 45 cm) Pigeonpea + Chia (1:3)	306.07	61.60	220.42
T_{13}:	Field bean (Sole crop- 45 cm × 15 cm)	282.24	79.80	321.40
T_{14}:	Vegetable soybean (Sole crop – 30 cm × 10 cm)	318.62	107.20	316.60
T_{15}:	Chia (Sole crop – 45 cm × 15 cm)	303.56	86.30	283.60
S.Em.±		10.55	2.548	9.085
CD (5%)		NS	7.381	26.319

Note: *NR: Normal row, PR: Paired row, NS: Non-significant*

Table 8. Uptake of total nitrogen, phosphorous and potassium by the crops as influenced by planting geometry and intercrops in pigeonpea based cropping system

Treatment		Nutrient uptake (kg ha^{-1})					
		Pigeonpea			Intercrop		
		N	P	K	N	P	K
T_1:	NR (120 cm × 30 cm) Pigeonpea (Sole crop)	61.24	8.98	80.12	-	-	-
T_2:	NR (120 cm × 30 cm) Pigeonpea + Field bean (1:2)	62.38	9.56	82.40	67.14	27.00	30.74
T_3:	NR (120 cm × 30 cm) Pigeonpea + Vegetable soybean (1:3)	65.47	9.84	83.37	37.58	16.80	28.42
T_4:	NR (120 cm × 30 cm) Pigeonpea + Chia (1:2)	57.45	7.86	74.12	90.63	31.32	60.04
T_5:	PR (120/60 cm × 30 cm) Pigeonpea (Sole crop)	82.48	12.60	102.80	-	-	-
T_6:	PR (120/60 cm × 30 cm) Pigeonpea + Field bean (1:2)	76.65	12.20	98.36	74.45	32.60	32.34
T_7:	PR (120/60 cm × 30 cm) Pigeonpea + Vegetable Soybean (1:3)	74.32	11.60	96.62	39.25	20.56	29.45
T_8:	PR (120/60 cm × 30 cm) Pigeonpea + Chia (1:2)	58.90	8.34	76.45	93.86	38.62	58.32
T_9:	PR (150/60 cm × 45 cm) Pigeonpea (Sole crop)	72.71	11.20	93.20	-	-	-
T_{10}:	PR (150/60 cm × 45 cm) Pigeonpea + Field bean (1:3)	70.56	10.80	91.70	78.45	32.36	38.54
T_{11}:	PR (150/60 cm × 45 cm) Pigeonpea + Vegetable Soybean (1:4)	68.65	10.60	91.50	40.48	21.42	30.56
T_{12}:	PR (150/60 cm × 45 cm) Pigeonpea + Chia (1:3)	58.56	8.24	78.60	98.34	38.53	65.48
T_{13}:	Field bean (Sole crop- 45 cm × 15 cm)	-	-	-	83.12	41.00	44.34
T_{14}:	Vegetable soybean (Sole crop – 30 cm × 10 cm)	-	-	-	46.12	23.45	33.06
T_{15}:	Chia (Sole crop – 45 cm × 15 cm)	-	-	-	105.48	40.20	96.48
S.Em.±		2.33	0.35	3.03	NA	NA	NA
CD (5%)		6.84	1.02	8.89	-	-	-

Note: *NR: Normal row, PR: Paired row, NA: Not analysed*

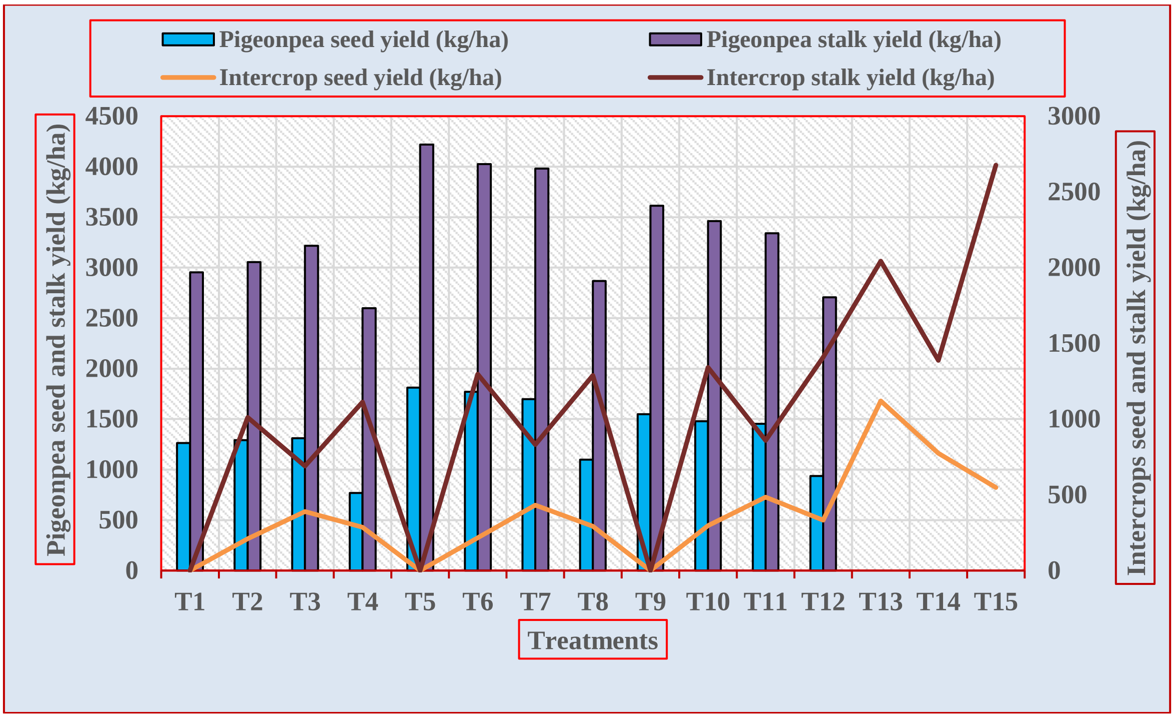

Fig. 1. Yield of pigeonpea and component crops as influenced by planting geometry and intercrops in pigeonpea-based intercropping system

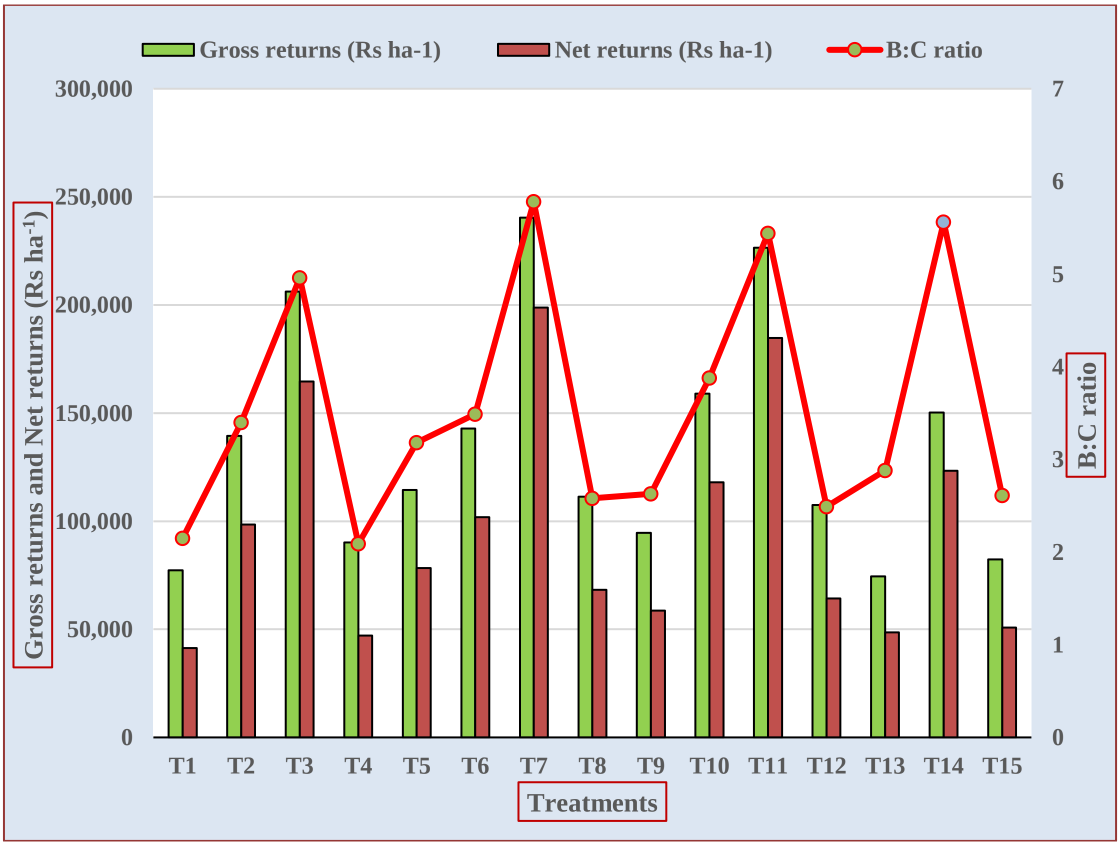

Fig. 2. Economics of pigeonpea equivalent yield as influenced by planting geometry and intercrops in pigeonpea based cropping system

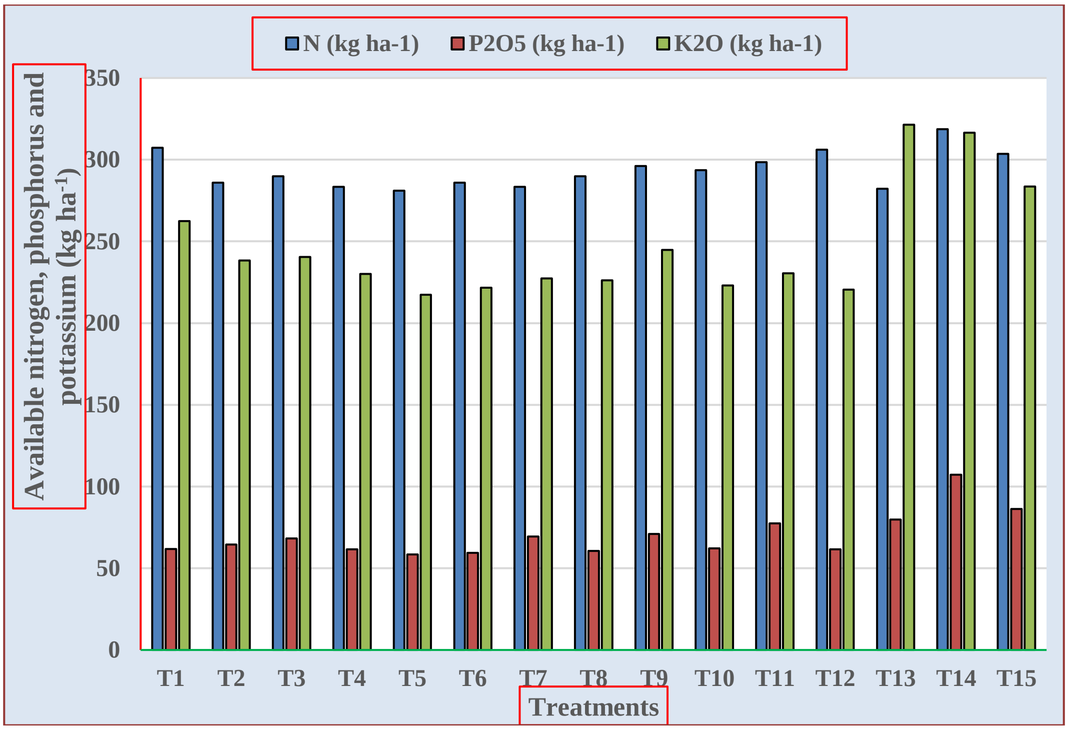

Fig. 3. Available nitrogen, phosphorous and potassium content in soil after harvest of crop as influenced by planting geometry and intercrops in pigeonpea based cropping system

Plates of Experimental plot

Plate 1. General view of experimental plot at 45 DAS

Plate 2. General view of experimental plot at 90 DAS

Plate 3. Paired row (120/60 cm × 30 cm) Sole Pigeonpea

Plate 4. Paired row (120/60 cm × 30 cm) Pigeonpea + Vegetable soybean (1:3)

Plate 5. Paired row (120/60 cm x 30 cm) Pigeonpea + Fieldbean (1:2)

Plate 6. Paired row (120/60 cm x 30 cm) Pigeonpea + Chia (1:2)

4. CONCLUSION

Based on the results it can be concluded that paired row pigeonpea with vegetable soybean at 120/60 cm x 30 cm recorded higher dry matter production, pigeonpea equivalent yield, gross returns, net returns, B:C ratio and nutrient uptake of NPK. It was found to be optimum and profitable and produced higher grain yield in pigeonpea + vegetable soybean at 1: 3 ratio under intercropping situation [13].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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