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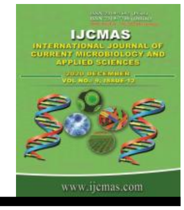

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Feasibility and Possibility of Transplanted Pigeonpea (*Cajanus cajan* L.) under Different Spacing and Nutrient Management Practices

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System of pigeonpea intensification, Transplanting, Vermicompost, Integrated Nutrient Management

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A field experiment was conducted during *Kharif* seasons of 2018-19 and 2019-20 at N. E. Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture & Technology, Pantnagar (Uttarakhand). The experiment was laid out in Split Plot Design with three replications having four planting methods as the main plot treatments viz; Conventional Sowing at 60 x 20 cm, Transplanting at 60 x 20 cm, 90 x 40 cm and 90 x 60 cm, and three nutrient management practices as Sub plot treatments viz; 100 % RDF (12:32:16 NPK fertilizer @ 150 kg ha^{-1}), Vermicompost at 5 ton ha^{-1} and 50% RDF + Vermicompost at 2.5 ton ha^{-1}. The test variety of used was ‘Pant Arhar 291’. The growth, yield, soil quality and economics of pigeonpea crop were found to be significantly influenced by various planting methods and nutrient management practices. Transplanting at 90 x 40 cm recorded the highest grain yield during both the years due to relatively higher plant population per unit area. The grain yield was 32.6 and 34.7 % higher over that of the Conventional Sowing at 60 x 20 cm during 2018-19 and 2019-20, respectively. The combination of inorganic and organic sources led to significantly better microbial population along during both the years. The maximum gross returns were obtained in case of Transplanting at 90 x 40 cm spacing. Among the nutrient management practices, the gross returns were highest with 50% RDF + Vermicompost at 2.5 ton ha^{-1}. Thus for sustained productivity of pigeon pea, it can be transplanted at 90 x 40 cm spacing and for nutrient application integration of 50% RDF + Vermicompost at 2.5 ton ha^{-1} could be taken as the most promising practices for System of Pigeonpea Intensification.

Introduction

Since ancient time, pulses are a fundamental component of the global cropping system after cereals and oilseeds particularly in the Indian context. The *dal* which is a necessary constituent of human diets in India is actually the pulse grains in the form of splits as a rich protein resource (pulses protein content 20 - 30%). A dietary mixture of cereals and pulses together provides an advanced biological value, than their sole consumption. The global pulse production accounts for 61.5 million ton expanding over an area of 70.6 million hectare with an average productivity of 806 kg ha^{-1}. India has a total area of 29 million hectares under pulses, which accounts to a production of 25.2 million tones, having an average productivity of 841 kg ha^{-1} (Ministry of Agri & FW, 2018).

Pigeonpea [*Cajanus cajan* (L.) Millsp.] also known as arhar, tur, redgram, congopea, no eye pea *etc*., is a pre-dominant pulse crop in India. It is a perennial short lived multipurpose shrub legume, belonging to leguminaceae family cultivated as an annual crop across the world in both tropical as well as sub-tropical regions. The nutritive profile of pigeon pea is; 55.7, 21.0, 5.1, 2.3 and 8.2% carbohydrate, protein, soluble sugar, fat & mineral and crude fibre, respectively. The protein digestibility of pigeon pea is also high accounting for about 66.8 percent (Saxena, 2010). 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 4.43 million hectares with production accounting to 4.25 million tonnes, having average productivity of 937 kg ha^{-1} (Ministry of Agri & FW, 2018). However, the overall productivity of pigeonpea has remained between 637 to 813 kg ha^{-1} for last several decades (Agriculture statistics at a glance, 2015). Being a deep rooted crop it acts as a “Biological plough”.

The present productivity of pegionpea is quite low and largely owing to abiotic stresses related to soil moisture content and fertility. The growth and development of any crop is influenced by availability of different growth factors *i.e.*, light, temperature, moisture and nutrient availability. The production, accumulation and translocation of the metabolites from source to sink is primarily the product of its genetics and available environment, whose efficiency is enhanced by adopting proper agronomic management, thereby harnessing the various resources in order to achieve higher production. The main agronomic manipulations affecting the crop development and yield are- timely sowing or planting, competent planting methods, maintenance of optimum plant population and planting geometry (Chaudhary and Thakur, 2005). The yield in pigeonpea is an integrated output of different yield attributing characters and plant population, which is in turn manipulated by planting geometry. Yield improvement can alternatively be achieved by reducing external input dependence rather focusing on mobilizing the biological processes and potentials that are available in existing plant and soil systems.

A great hope for improving the productivity of Pigeonpea has been witnessed in the concept System of Pigeon pea Intensification (SPI), which can help to combat the climatic aberrations experienced by the crop (Praharaj *et al.,* 2015). The concept of SPI deals with maximization of yield and net return per unit area of pigeonpea through adoption of a low input-intensive technology. This depends on external inputs to a minimum extent rather induces larger, better-functioning root systems helping in better resource utilization and mobilization towards yield. This system has a number of advantages; including need for less number of seeds for sowing, less need of water and nutrients, ease in sowing by manual dibbling through poly bags etc. This technique has been found quite stable under both abiotic and biotic stresses. For harnessing the potential of a crop like pigeon pea (having branching habit), planting at proper spacing is a pre-requisite to make best use of the available resources.

The optimum spacing depends upon the nature of variety, soil type and prevailing climatic conditions. Sujatha (2017) found transplanting of pigeonpea at 120 x 30 cm as the most optimum spacing for rainfed situations. Sajjan (2018) found 120 x 30 cm and 90 x 30 cm as the optimum spacing for transplanting of pigeonpea at Vijayapur, Dharwad, Karnataka. In present day agriculture, rampant use of inorganic with minimum or no organic manure, the cultivable lands are depleted in organic C content and becoming unfertile and exerting multiple nutrient deficiencies. Despite the gains of the green revolution for achieving self sufficiency in food grain production, intensive cropping practices coupled with extensive chemical inputs usage made an adverse impact on natural resource base leading to a decline in crop productivity as well as food quality. At this juncture, there is a need device a nutrient management practice that can last for long without affecting the soil and environmental health. Balanced fertilization is necessary to increase the productivity of Pigeon pea. The NPK uptake of pigeon pea crop accounts to about 63.3 kg N, 15.8 kg P_2O_5 and 49.8 kg K_2O (Tamboli *et al.,* 1995). Proper nutrient management of pigeon pea provides a great scope for enhancing yield and productivity by making up for the crop nutrient demand. By Balanced nutrient management not only we can adequately meet up the crop requirement but also prevent soil degradation by reducing the leaching losses helping in improving the nutrient availability and use efficiency.

Integrating inorganic, organic and bio-fertilizers are essential in realizing the higher pigeonpea yield and reducing cost of production has been reported by Reddy *et al.,* (2011). The work of various research workers indicated that integrated nutrient management practice may play significant role to promote growth and productivity of pigeonpea in a sustainable basis as well as soil health.Vermicompost is a brilliant source for this purpose as it not only improvises the yields but also causes a substantial improvement in soil microbiological community development by providing organic matter along with various growth promoting enhancers supporting their growth and development. The vermicompost contains several growth enhancing hormones *i.e.,* auxins, cytokinins and gibberlins along with metabolites, vitamins *viz.,* Vitamin D and B and micro elements which directly promote plant growth. Other than having inherent higher content of N, P, K, Ca and Mg they amend the soil structure helping in release of fixed Ca, Mg and several micronutrients (Orozzo *et al.,* 1996). The population of microorganisms in vermicompost is higher than traditional composts and the type of microbes found depends on the types of earthworm species used for composting. The common growth enhancing microbes found are as follows, *Pseudomonas oxalaticus, Rhizobium japonicum, Oseudomonas putida,* NPK availability enhancers *viz., Azospirillum sp., Azotobacter sp., Nitrosomonas sp., Nitrobacter sp.* and *phosphate solubulisers* (Gopal *et al.,* 2009; Pathama and Sakthivel, 2012). Somashekar (2017) suggested that application of Vermicompost @ 5 t ha^{-1} in Pigeon pea crop at Raipur, Chattishgarh over farmer's practice of application of 100 % RDF.

Materials and Methods

A field experiment was conducted during *Kharif* seasons of 2018-19 and 2019-20 at N. E. Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture & Technology, Pantnagar (Uttarakhand). The experiment was laid out in Split Plot Design with three replications having four planting methods as the main plot treatments viz; Conventional Sowing at 60 x 20 cm, Transplanting at 60 x 20 cm, 90 x 40 cm and 90 x 60 cm, and three nutrient management practices as Sub plot treatments viz; 100 % RDF (12:32:16 NPK fertilizer @ 150 kg ha^{-1}), Vermicompost at 5 ton ha^{-1} and 50% RDF + Vermicompost at 2.5 ton ha^{-1}. The soil of the experimental site was silty clay loam in texture being low in available nitrogen (256.2

and 261.5 kg/ha), high in available phosphorus (26.1 and 25.3 kg/ha), low in available potassium (149.6 and 153.3 kg/ha), and high in organic carbon (0.80 and 0.87 %) with a neutral soil reaction (pH 7.24 and 7.49) during the two years of study.The test variety of pigeonpea used was 'Pant Arhar 291'. Seeds treated with thiram @ 2 g + carbendazim @ 1 g/kg seed for protection against soil borne diseases. Seeds were inoculated with *Rhizobium* and *PSB* @ 20 g of each per kg of seeds to enhance nodulation and phosphorous use efficiency. The conventional crop was sown by line placement of seeds manually where as the nursery for the transplanted crop was sown on the same date. The 21 day old seedlings were transplanted in the field on the third week of June with onset of monsoon according to treatments. The furrows were prepared at spacings of 60 x 20 cm, 90 x 40 cm and 90 x 60 cm as per the treatment layout with furrow opener. One healthy seedling per hill was placed as per the inter row spacing according to the main plot treatment in furrows and later raised beds were made with Phaura. Initally use of auger was done to make holes on raised beds at required spacing for one plot but as it required more labour and time the above mentioned alternate method was preferred. One hand weeding and 1 mild irrigation after sowing and transplanting were undertaken during the entire crop period. One spray of pendimethalin @ 1ml/L was also taken up. One spray of each, monocrotophos 36 SL @ 1ml/L and Indoxacarb @ 1.5 ml/L was also done.When the plants turned yellow and the pods to brown colour, the crop from border rows and net plots were harvested separately. The pods of each treatment were sun dried thoroughly and threshed manually. Then the seeds were dried and cleaned. The stalk from each net plot was harvested and sun dried.

The climate of the region is broadly humid sub-tropical with harsh winters and hot dry summers. During hot summer, the maximum temperature exceeds 40°C, while in winter the minimum temperature occasionally touches 1°C. The monsoon usually starts in the third week of June and continues till the middle of September at Pantnagar. Frost is expected from late December to February. The mean relative humidity remains almost 80-90 per cent from mid-June to end of February and then it steadily decreases to 50 per cent by the first week of May and remains same till mid June. Weather parameters prevailing during the crop season were obtained from the meteorological observatory located in the N.E. Borlaug Crop Research Centre of the university which is presented in Table 1 and 2 for the *Kharif* season 2018-19 and 2019-20, respectively.

A recommended dose of 150 kg ha^{-1} for100 % RDF was applied through NPK mix as per treatment as basal at the time of sowing. The site specific vermicompost application and incorporated on per plant basis at the time of transplanting. The details of amount of nutrient supplied through applied rate are given in Table 3. The content of N: P_2O_5: K_2O (%) is 12:32:16 in NPK mix and 1.91: 1.18: 1.51, respectively.

The observations were taken using destructive and non-destructive sampling methods. Five plants in each net plot were selected and tagged in each treatment for recording periodical observations on growth parameters at 30 days interval and yield attributes at harvest. For recording leaf area and dry matter production, destructive sampling was done by taking 3 plants each time from the border rows. The data recorded on various parameters of crop during the course of investigation was statistically analyzed following the analysis of variance for randomized block design as suggested by Kwanchai A. Gomez and Arturo A. Gomez (1983). Statistical significance was tested with 'F' value at 5 % level of probability. Critical Difference (CD) for the significant sources of variation was calculated at 5 % level of significance.

Results and Discussion

The growth, soil microbial population, yield and gross returns of pigeonpea crop were found to be significantly influenced by various planting methods and nutrient management practices (Fig. 1 and Table 1–6).

Effect on Plant height and leaf area

At 30 DAS, Conventional sowing at 60 x 20 cm (C_1) treatment resulted in plants of tallest stature in both the years (36.7 & 40.7 cm). This was followed by Transplanting at 60 x 20 cm (T_1) (30.4 & 32.9 cm), Transplanting at 90 x 40 cm (T_2) (30.2& 32.7 cm) and Transplanting at 90 x 60 cm (T_3) (30.1 & 32.6 cm), which were also statistically at par with each other in 2018-2019. But at 60 DAS the highest plant height of pigeonpea was registered with Transplanting at 60 x 20 cm (T_1), which was comparable with the next better treatment Transplanting at 90 x 40 cm (T_2) in 2018. Transplanting at 90 x 60 cm (T_3) and Conventional sowing at 60 x 20 cm (C_1) recorded the lowest plant height and were also found to be at par with each other in 2018. The results were also same in 2019. Similar findings were also recorded by Panda (2017), Sujatha (2017) and Somashekar (2017). The plant height of pigeonpea was not influenced significantly by nutrient management practices at 30 DAS, in both 2018 and 2019. At later stages of growth *i.e.* 60 DAS the plants of tallest stature were recorded under 50 % RDF + Vermicompost at 2.5 ton ha^{-1}(N_3) which was followed by Vermicompost at 5 ton ha^{-1}(N_2) and was on par with the same. The plants of lowest stature were recorded by 100 % RDF (18: 48: 24 kg N: P_2O_5: K_2 O ha^{-1}) (N_2) which were at par statistically with the later. At 30 DAS, Conventional planting system recorded significantly highest leaf area per plant. Among treatments leaf area per plant didn't vary significantly during both the years. At 60 days of recording transplanted pigeon-pea at 90x60 cm recorded significantly higher leaf area per plant as compared to other planting systems during both the years. It was followed by Transplanting at 90x40 cm with a significant reduction as compared to the previous treatment. Further, Transplanting at 60x20 cm and conventional sowing at 60 x 20 cm didn't show any significant differences in leaf area per plant. However, both were found to be significantly inferior as compared to transplanting at 90x40 cm at all the stages in both the years.

The leaf area per plant was also affected significantly by nutrient management practices at all the stages. The treatment 50 % RDF + Vermicompost at 2.5 ton ha^{-1}(N_3) registered the maximum value and was followed by Vermicompost at 5 ton ha^{-1}(N_2), which in turn remained on par with each other. Further leaf area per plant observed in VC alone didn't differ significantly with application of 100% RDF.

Transplanting of 21 day old seedling helped in better establishment of the crop further the wider spacings might have reduced the competition for space, light and nutrients due to reduced plant population leading to a more vibrant luxurious growth in terms of leaf number and size. Further in close spaced transplanted crops there is higher competition for nutrients which leads to greater upright growth producing a higher plant height whereas, in wider spacings there is lesser competition leading to more lateral growth than upright development thus resulting in lesser plant height. Salakinkoppa and Patil (2010), Pavan *et al.,* (2011), Goud and Andhalkar (2012), Praharaj *et al.,* (2015), Mohanadas (2016), Panda (2017) and Sujatha (2017) also reported similar results. The rapid release increases availability of nutrients particularly nitrogen, an important constituent of protoplasm, due to presence of 50 % RDF leads to amplified auxin and cytokinin availability which are the main contributors for cell division, multiplication and elongation.

The higher metabolic activity owing to presence of both growth promoting hormones and nutrients in vermicompost might be another contributing factor. The results are in accordance with Gholve *et al.*, (2005), Kumawat *et al.*, (2013), Mallikarjun (2012), Hajari *et al.*, (2015), Pal *et al.*, (2016) and Somasekhar (2017).

Effect on days to 50 per cent flowering and days to maturity

Days to 50 per cent flowering and days to maturity of pigeonpea were significantly influenced by various planting methods and nutrient management practices. The transplanted systems took significantly greater time to obtain 50% flowering and were on average higher by 7 days in comparison to conventional planting system during both the years. The transplanting at 60 x 20 cm took the highest time to reach 50% flowering, followed by transplanting at 90 x 40 cm and 90 x 60 cm. All three of the treatments were statistically at par. The conventional planting method at 60 x 20 cm took the significantly lowest number of days to reach 50% flowering in both 2018 and 2019. Among the nutrient management practices, the application of VC alone @ 5 t/ha took the highest number of days to reach flowering. This was followed by 50% RDF + VC @ 2.5 t/ha and 100% RDF which were on par with each other in both the years. The transplanted crop matured later by 9-15 days than the conventional planting system crop. There was a significant difference observed during both 2018 and 2019. The transplanting at 60 x 20 cm took the highest time to reach maturity and was at par with transplanting at 90 x 40 cm. The transplanting at 90 x 60 cm took significantly lesser time than these previous treatments but was higher than the conventional sowing at 60 x 20 cm. The conventional sowing at 60 x 20 reached maturity earliest of all treatments and was significant to all in both the years. The 50% RDF + VC @2.5 t/ha was at par with 100% RDF statistically. Those were followed by VC @ 5 t/ha which matured earliest and took significantly lowest time in 2018 and 2019.

The transplanted pigeonpea had higher growth has a longer vegetative and reproductive period than that of conventional crop. Further the availability of nitrogen and plant growth promoting hormones might have further caused a boost in the vegetative growth therby delaying the flowering and maturity too. The results can be corroborated with the findings of Jamadar *et al.*, (2014), Sajjan (2018), Mallikarjun (2012).

Effect on microbial population

The population of bacteria, fungi and *actinomycetes* were highest for transplanting at 90 x 60 cm and 90 x 40 cm which didn't vary significantly from each other in 2018 and 2019. The populations recorded in transplanting at 60 x 20 cm have significantly higher values than conventional sowing at 60 x 20 cm, but was on par with 90 x 40 cm. The microbial population in conventional planting systems in general reduced significantly than transplanting systems in both the years. The various nutrient management practices showed a significant variation between each other in 2018 and 2019. The 50% RDF + VC @ 2.5 t/ha was at par with VC @5 t/ha statistically and recorded significantly higher values than 100% RDF application during both the years.

Table.1 Standard Meteorological Week' average weather data from May, 2018 to November, 2018 recorded at G. B. Pant University of Agriculture and Technology

Month	Date	Year	Metero Week No. (2018)	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Number of rainy days	Sunshine (hours day^{-1})	Wind Velocity (Km hr^{-1})	Evaporation (mm day^{-1})
				Maximum	Minimum	712 am	1412 pm					
May-Jun	'28-03	2018	22	35.5	23.0	69.7	55.4	38.4	3	7.1	9.6	**8.3**
Jun	'04-10	2018	23	35.1	26.0	82.1	63.7	87.6	2	7.7	7.5	**8**
Jun	'11-17	2018	24	34.6	26.2	84.9	63.1	42.8	2	5.2	5	**5.7**
Jun	'18-24	2018	25	37.2	26.1	76.4	44.7	0	0	7.9	6	**6.8**
Jun-Jul	'25-01	2018	26	35.9	26.6	80.7	67.7	18.2	1	6.4	7.5	**7.3**
Jul	'02-08	2018	27	32.6	25.4	90.0	70.0	18.0.8	3	6	3.5	**5.6**
Jul	'09-15	2018	28	32.5	26.0	88.0	78.4	173.2	3	3.1	6.1	**4.2**
Jul	'16-22	2018	29	33.3	26.9	82.1	73.1	79.6	2	6.7	3.7	**6.6**
Jul	'23-29	2018	30	31.2	25.7	91.0	80.0	169	4	2.2	5.6	**4.6**
Jul-Aug	'30-05	2018	31	29.7	24.1	93.6	84.0	218.1	6	1	2.2	**3.5**
Aug	'06-12	2018	32	30.9	24.9	90.4	79.7	126.4	3	3.6	2.6	**4.3**
Aug	'13-19	2018	33	31.9	26.1	89.0	71.7	73.4	1	4	1.5	**3.3**
Aug	'20-26	2018	34	30.9	25.5	95.1	83.0	160.8	5	3.2	1.1	**4.4**
Aug-Sep	'27-02	2018	35	30.7	25.5	92.4	81.0	86.8	3	2	3.3	**2.7**
Sep	'03-09	2018	36	32.3	25.3	90.4	76.3	76.6	2	4.7	5.3	**3.9**
Sep	'10-16	2018	37	31.9	24.3	93.0	77.6	15.6	2	5.6	6.1	**3.9**
Sep	'17-23	2018	38	32.1	22.6	90.1	73.4	49.2	1	6.8	6.6	**4**
Sep	'24-30	2018	39	30.4	22.0	91.3	69.7	80.6	1	4.6	5.4	**3.1**
Oct	'01-07	2018	40	32.6	18.5	84.3	60.1	0	0	9.1	4.6	**4**
Oct	'08-14	2018	41	30.9	17.1	82.7	61.4	2.6	0	7.3	4.7	**3.5**
Oct	'15-21	2018	42	30.7	14.3	86.9	59.1	0	0	7.8	3.5	**3.3**
Oct	'22-28	2018	43	29.6	12.0	90.4	50.7	0	0	8.3	3.4	**3.1**
Oct-Nov	'29-04	2018	44	29.9	13.7	87.7	54.3	4.2	1	7.1	3.2	**2.7**
Nov	'05-11	2018	45	27.5	11.7	93.9	54.0	0	0	7.7	2.8	**2.4**
Nov	'12-18	2018	46	26.5	11.8	93.3	63.1	0	0	6.5	2.3	**2.2**
Nov	**'19-25**	**2018**	**47**	**26.3**	**10.5**	**93.4**	**54.3**	**0**	**0**	**7.7**	**1.8**	**2.6**

Table.2 Standard Meteorological Week' average weather data from May, 2019 to November, 2019 recorded at G. B. Pant University of Agriculture and Technology

Month	Date	Year	Metero Week No. (2018)	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Number of rainy days	Sunshine (hours day^{-1})	Wind Velocity (Km hr^{-1})	Evaporation (mm day^{-1})
				Maximum	Minimum	712 am	1412 pm					
May-Jun	'28-03	2019	22	40.1	23.0	50.1	28.3	0	0	9.8	8.7	**11.1**
Jun	'04-10	2019	23	38.9	26.0	63.4	37.0	23.4	1	10	6.9	**10.1**
Jun	'11-17	2019	24	39.0	25.1	69.3	36.4	18.4	1	9.4	8.6	**10.9**
Jun	'18-24	2019	25	35.9	24.2	76.6	52.1	62.2	2	8.2	7	**7.2**
Jun-Jul	'25-01	2019	26	34.6	25.6	76.9	54.4	153	1	8.5	5	**7.2**
Jul	'02-08	2019	27	33.9	26.1	79.1	68.6	30.8	3	4.7	4.7	**5.2**
Jul	'09-15	2019	28	31.0	25.3	94.6	75.6	144.9	5	1.5	5	**4.2**
Jul	'16-22	2019	29	32.7	25.7	84.3	64.3	41.2	1	5.4	3	**4.2**
Jul	'23-29	2019	30	32.4	26.5	84.9	71.0	16.8	3	3.8	6.7	**4.6**
Jul-Aug	'30-05	2019	31	33.3	26.0	88.1	67.4	108.2	4	4.8	5	**4.9**
Aug	'06-12	2019	32	32.7	25.8	88.1	70.1	116.5	3	5.1	3.8	**4.7**
Aug	'13-19	2019	33	32.0	25.4	89.3	74.1	51.2	4	5.2	5.8	**4.8**
Aug	'20-26	2019	34	32.3	24.7	89.9	65.6	37.8	1	5.3	2.4	**4.1**
Aug-Sep	'27-02	2019	35	33.8	25.7	85.6	66.1	174.6	2	6.1	1.9	**4.5**
Sep	'03-09	2019	36	33.1	25.3	90.0	72.0	112.2	2	5.8	3.5	**4.3**
Sep	'10-16	2019	37	33.1	25.7	89.4	69.9	7.8	1	5.5	3.5	**4.3**
Sep	'17-23	2019	38	32.1	22.4	88.1	62.4	14.2	2	7	4.5	**3.6**
Sep	'24-30	2019	39	30.9	23.0	88.0	65.1	6.2	1	6.1	1.8	**3.6**
Oct	'01-07	2019	40	30.9	21.3	92.3	57.3	0	0	7.6	1.9	**2.9**
Oct	'08-14	2019	41	31.9	18.8	88.1	47.3	0	0	8.6	2.4	**3.2**
Oct	'15-21	2019	42	31.0	18.0	85.7	49.6	0	0	6	1.2	**2.7**
Oct	'22-28	2019	43	29.6	16.2	91.9	46.7	0	0	6.5	2.2	**2.8**
Oct-Nov	'29-04	2019	44	29.2	17.1	89.4	57.1	0	0	1.2	2.4	**2**
Nov	'05-11	2019	45	29.1	14.0	85.3	43.7	0	0	6	2.7	**2.4**
Nov	'12-18	2019	46	29.0	13.3	91.4	44.3	0	0	6.6	3.2	**2.2**
Nov	**'19-25**	**2019**	**47**	**25.0**	**11.5**	**94.0**	**47.3**	**0**	**0**	**4.7**	**1.8**	**2.1**

Table.3 Amount of nutrient supplied through various sources

S. No.	Particulars	Application Rate	N (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})
1.	100 % RDF (NPK Mix)	150 kg ha^{-1}	18	48	16
2.	100 % Vermicompost	5 t ha^{-1}	95	55	75
3.	50 % RDF (NPK Mix)	75 kg ha^{-1}	9	24	8
4.	50 % Vermicompost	2.5 t ha^{-1}	47.5	27.5	37.5

Table.4 Plant height and leaf area, dry matter production of pigeonpea at 30 and 60 DAS stages as influenced by various planting methods and nutrient management practices

Treatments	Plant height (cm)							
	30 DAS		60 DAS		30 DAS		60 DAS	
	2018	2019	2018	2019	2018	2019	2018	2019
Factor A: Planting Method and Geometry								
C_1- Conventional Sowing 60 cm x 20 cm	36.7	40.7	105.6	113.6	1914	2008	2812	**3232**
T_1- Transplanting 60 cm x 20 cm	30.4	32.9	124.1	144.8	1628	1719	3032	**3332**
T_2- Transplanting 90 cm x 40 cm	30.2	32.7	113.9	135.0	1528	1585	9520	**10780**
T_3- Transplanting 90 cm x 60 cm	30.1	32.6	105.5	112.1	1483	1458	14814	**17244**
SEm±	1.0	1.0	3.8	7.2	79	61	257	**330**
CD (P=0.05)	3.4	3.6	13.3	24.9	277	214	891	**1140**
Factor B: Nutrient Management								
N_1- 100 % RDF (18 kg N: 48 kg P_2O_5: 24 kg K_2O ha^{-1})	31.6	34.5	99.3	112.4	1430	1511	7164	**8266**
N_2- Vermicompost at 5 ton ha^{-1}	31.9	34.8	113.4	126.6	1631	1651	7495	**8598**
N_3- 50 % RDF + Vermicompost at 2.5 ton ha^{-1}	32.1	35.1	123.5	140.1	1853	1914	7974	**9076**
SEm±	0.5	0.5	3.5	4.8	136	40	216	**169**
CD (P=0.05)	**NS**	**NS**	**10.49**	**14.26**	**398**	**118**	**630**	**491**

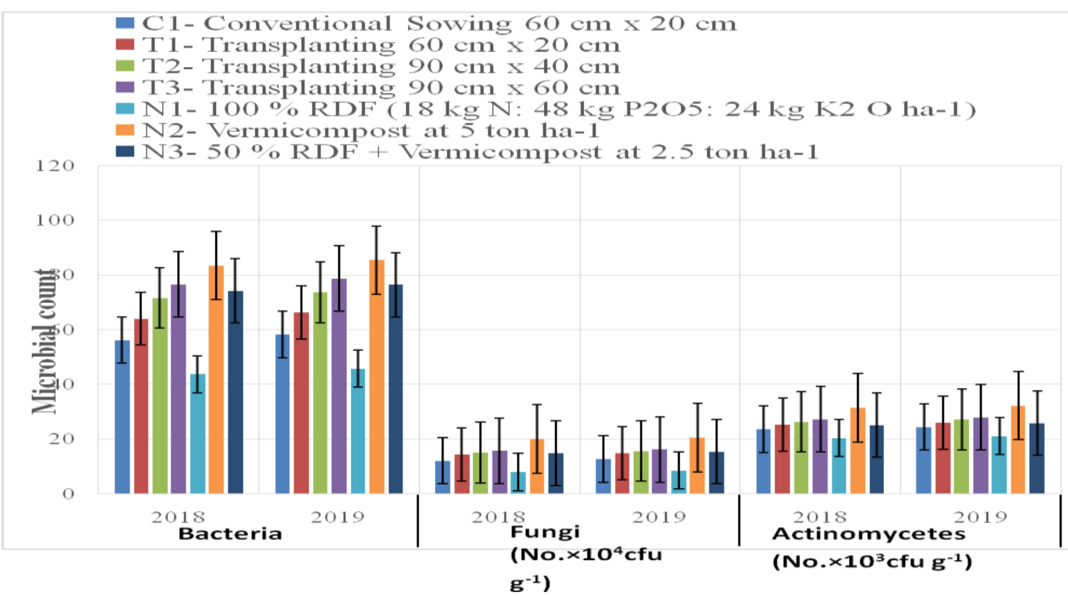
Table.5 Days to 50 per cent flowering and maturity of pigeonpea as influenced by various planting methods and nutrient management practices

Treatments	Days to 50 per cent flowering		Days to maturity	
	2018	2019	2018	2019
Factor A: Planting Method and Geometry				
C_1- Conventional Sowing 60 cm x 20 cm	79	80	158	**159**
T_1- Transplanting 60 cm x 20 cm	89	89	173	**176**
T_2- Transplanting 90 cm x 40 cm	88	87	172	**175**
T_3- Transplanting 90 cm x 60 cm	86	86	167	**170**
SEm±	1.1	1.6	0.85	**1.3**
CD (P=0.05)	4.1	5.6	2.9	**4.8**
Factor B: Nutrient Management				
N_1- 100 % RDF (18 kg N: 48 kg P_2O_5: 24 kg K_2O ha^{-1})	87	87	170	**172**
N_2- Vermicompost at 5 ton ha^{-1}	84	84	166	**168**
N_3- 50 % RDF + Vermicompost at 2.5 ton ha^{-1}	85	86	168	**170**
SEm±	0.5	0.8	1.4	**1.0**
CD (P=0.05)	**1.4**	**2.4**	**4.1**	**2.9**

Table.6 Grain yield, stalk yield, stick yield and biological yield and harvest index of pigeonpea as influenced by various planting methods and nutrient management practices

Treatments	Grain Yield (kg ha^{-1})		Gross Returns	
	2018	**2019**	**2018**	**2019**
Factor A: Planting Method and Geometry				
C_1- Conventional Sowing 60 cm x 20 cm	1865	2010	1,05,832	**1,16,567**
T_1- Transplanting 60 cm x 20 cm	2106	2234	1,19,541	**1,29,566**
T_2- Transplanting 90 cm x 40 cm	2475	2707	1,40,431	**1,57,000**
T_3- Transplanting 90 cm x 60 cm	2279	2493	1,29,358	**1,44,613**
SEm±	72	109	4137	**6374**
CD (P=0.05)	252	380	14317	**22057**
Factor B: Nutrient Management				
N_1- 100 % RDF (18 kg N: 48 kg P_2O_5: 24 kg K_2O ha^{-1})	2032	2216	1,15,321	**1,28,538**
N_2- Vermicompost at 5 ton ha^{-1}	2193	2382	1,24,453	**1,38,127**
N_3- 50 % RDF + Vermicompost at 2.5 ton ha^{-1}	2319	2485	1,31,599	**1,44,145**
SEm±	63	55	3587	**3203**
CD (P=0.05)	**184**	**161**	**10470**	**9350**

Fig.1 Microbial content in soil as influenced by various planting methods and nutrient management practices in pigeonpea crop



The population of microorganisms in vermicompost is higher than traditional composts and the type of microbes found depends on the types of earthworm species used for composting. The common growth enhancing microbes found are as follows, *Pseudomonas oxalaticus, Rhizobium japonicum, Oseudomonas putida,* NPK availability enhancers *viz., Azospirillum sp., Azotobacter sp., Nitrosomonas sp., Nitrobacter sp.* and *phosphate solubulisers* (Gopal *et al.,* 2009; Pathama and Sakthivel, 2012).

Effect on grain yield

The grain yield was affected significantly during both the years, both by planting systems and nutrient management practices. Transplanting of pigeon-pea at 90x40 cm produced significantly highest grain yield during both the years being 2475 kg/ha in 2018 and 2707 kg/ha in 2019. Transplanting at 90x60 cm recorded the next higher grain yield being 7.924 and 7.91% lower, respectively in 2018 and 2019. The grain yield did not vary significantly between transplanting at 90 x 60 cm and 90 x 40 cm during both the years. Conventional sowing registered significantly lowest grain yield during both the years.

The reduction was 12.9, 22.1 & 32.7 % in 2018 and 11.1, 24.1 & 34.6 % in 2019, respectively against 60 x 20 cm, 90 x 60 cm and 90 x 40 cm, transplanting systems. Nutrient management practice of 50% RDF + VC @ 2.5 t /ha obtained the maximum grain yield (2319 kg/ha in 2018 and 2485 kg/ha in 2019) which was found to be at par with N_2 (2193 kg/ha in 2018 and 2382 kg/ha in 2019) during both the years. In the first year, N_2 and N_1 did not differ significantly for grain yield, while during second year, N_2 (2382 kg/ha) recorded significantly higher grain yield than N_1 (2216 kg/ha). The increase in grain yield with N_2 and N_3 over N_1 was xx and xx% in 2018 and xx and xx% during 2019.

Yield is the product of plant population per unit area and the single plant yield. Maximum yield can be obtained at the optimum density where competition between the plants is minimum by making better utilization of available space, light, moisture and nutrients more efficiently. Therefore transplanting at 90 x 40 cm gave better yields even though per plant yield is higher in transplanting at 90 x 60 cm. This planting geometry resulted in higher dry matter production and its accumulation in leaves, stem and pods owing to higher plant population than the widest spacing. Similar findings were also reported by Pavan *et al.,* (2009), Poornima *et al.,* (2009), Potdar *et al.,* (2010), Anilkumar *et al.,* (2011), Jamadar and Sajjan (2014), Mallikarjun (2012), Murali *et al.,* (2014), Singh and Kirar (2016) and Panda *et al.,* (2017). In integrated nutrient application the higher yield might be due to the cumulative effect of elevated growth stature as well as yield attributes under the condition of adequate nutrient supply, favouring the production of photosynthates coupled with better partitioning to the sink. Further application of vermicompost might have enhanced the activity of dehydrogenase, phosphatase and urease in the soil. Hence, the positive effect of combined application of vermicompost with RDF was reflected with higher grain and stalk yields. Pandey and Khuswaha (2009), Saritha *et al*, (2012), Kumawat *et al.,* (2013), Pandey *et al.,* (2013), Hajari *et al.,* (2015), Pal *et al.,* (2016), Somashekar (2017) and Sajjan (2018) also postulated similar views.

Effect on gross returns

The gross returns recorded were highest for transplanting at 90x40 cm which was followed by transplanting at 90x60 cm and was statistically at par with the same. Significantly lower gross returns were recorded for transplanting at 60x20 cm and conventional planting systems which didn't vary significantly from each other during both of the experimental years. The nutrient management practices affected gross returns significantly. The combined application of 50% RDF + VC @ 2.5 t /ha recorded highest gross returns and was at par with N_2 i.e., VC @ 5 t/ha which was the next better treatment. The lowest gross returns were recorded for N_1. However, N_1 was on par with N_2 statistically in both the years. Similar results were perceived by Gholve *et al.,* (2005), Patil *et al.,* (2007), Pandey *et al.,* (2013), Singh (2016) and Somashekar (2017).

The highest gross apprehended with transplanting at wider spacing and integrated usage of 50% RDF + vermicompost @ 2.5 t/ha might be due to the higher grain and stalk yields as well as lesser production costs in comparison to transplanting at closer spacing. The lowest gross returns were noticed to be conventional planting system due to the lowest grain and stalk yield. Similar results were perceived by Malik (2009), Poornima *et al.,* (2010), Goud and Andhalkar (2012), Priyanka *et al.,* (2013) and Singh and Kirar (2016).

Thus it can be concluded that Thus for sustained productivity of pigeon pea, it can be transplanted at 90 x 40 cm spacing and for nutrient application integration of 50% RDF + Vermicompost at 2.5 ton ha^{-1} could be taken as the most promising practices for System of Pigeonpea Intensification for higher yield, economics of pigeonpea along with maintenance of soil quality and fertility for the sustenance of soil ecology. Transplanting in many crops has advantage over direct seeding with respect to crop growth and yield. It is more true in rainfed farming areas of northern Karnataka, as the rainfall is not only scanty but also erratic. Thus, timely sowing and also soil moisture during different stages of crop growth becomes the most limiting factor in pigeonpea production. In order to ensure timely sowing and higher yields of System of Pigeonpea Intensification is one of the best agronomic management. The integration of organics and inorganics not onlyprovides better nutrients both macro and micro for longer period substantially but also enhances soil physico-chemico-biological properties. It's the better solution to the need of the hour *i.e.* intensifying pigeonpea yield.

Authors' Contributions

The work was carried out in collaboration with all authors. Author SSM carried out the entire experiment, recorded the observations regularly, performed the statistical analysis, wrote the protocol as well as the first draft of the manuscript. Author CB, AS, VKS and NP acted as the advisor and co-advisors in carrying out the experiment assisting SSM in design of experiment, clearing the doubts, providing all the guidance required for smooth conduction of the experiment. All the co-authors along with SSM managed the literature searches and recorded feedback as well as guided SSM in finalization of the manuscript by editing the same. All the authors read and approved the final manuscript.

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