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Effect of different intercrops on quality and nutrient uptake of organically grown pigeonpea

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Abstract
A field experiment was conducted during the *kharif* seasons of 2021 and 2022 on organically certified field at Organic Farming Research and Training Centre (OFRTC), Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, District Ahmednagar, (M.S.) on medium black soils to evaluate the performance of different crops in pigeonpea based intercropping system. The treatments comprised of seven sole cropping systems *viz*., T_1-Sole Pigeonpea, T_2-Sole Onion, T_3-Sole Cauliflower, T_4-Sole Greengram, T_5-Sole Soybean, T_6-Sole Sesame, T_7-Sole Pearlmillet and six pigeonpea based intercropping systems *viz*., T_8 - Pigeonpea + Onion (1:8), T_9 - Pigeonpea + Cauliflower (1:3), T_{10} - Pigeonpea + Greengram (1:5), T_{11} - Pigeonpea + Soybean (1:5), T_{12} - Pigeonpea + Sesame (1:5) and T_{13} – Pigeonpea + Pearlmillet (1:5). These treatments were randomized appropriately and each treatment replicated thricely during both the years of research trial. On the basis of two years experimental results, the nitrogen, phosphrous and potassium content (per cent) in seed and stover/stalk of Pigeonpea as well as protein content (per cent) in grains was not influenced significantly due to intercropping of different crops on pooled mean basis. While the total uptake (by seed and stover/stalk) of nitrogen (97.29, 102.73 and 100.01 kg ha^{-1}), phosphorus (11.72, 13.33 and 12.52 kg ha^{-1}) and potassium (55.01, 58.90 and 56.95 kg ha^{-1}) was recorded significantly highest with treatment T_1 (Sole Pigeonpea) as compared to rest of the intercropping system treatments during first year, second year and on pooled mean basis, respectively.

Keywords: Pigeonpea, intercropping system, quality, uptake

Introduction
Intercropping plays a crucial role in sustainable agriculture and global food production. This technique involves growing two or more crops simultaneously in the same area, enhancing cropping intensity in both time and space. By optimizing resource utilization, intercropping reduces risks, minimizes weed competition, and stabilizes yields, thereby increasing productivity per unit of land. Legume-cereal intercropping systems, in particular, are becoming popular as they diversify traditional cereal-based systems and boost profitability. Research on intercropping has been driven by the potential for higher yields and better use of solar energy and land resources, leading to greater returns.

Pigeonpea is an ideal base crop for intercropping with various crops such as cotton, sorghum, pearl millet, mungbean, urdbean, maize, soybean, and groundnut to enhance system productivity and soil health. As an effective cover crop, pigeonpea also helps control soil erosion by protecting it from direct rainfall (Mula and Saxena, 2010) [7]. Its initial slow growth rate and deep root system make pigeonpea well-suited for intercropping with fast-growing, early-maturing, shallow-rooted crops (Nandhini *et al*., 2015) [8]. Pigeonpea, due to its slow initial growth rate and low harvest index when grown as a sole crop, benefits significantly from being intercropped (Willey, 1979) [9]. Intercropping pigeonpea with other crops allows for more efficient resource use, enhancing productivity and profitability for numerous farming communities. Addressing the need to produce sufficient food, fuel, fiber, and other resources for the growing global population, particularly in developing countries, is critical. Land-based farming will need to provide over 90% of the required food (Darshan, 2008) [6].

Materials and Methods
The field experiment was conducted on organically certified field (certified from 2019-2020) at Organic Farming Research and Training Centre (OFRTC), Mahatma Phule Krishi

Vidyapeeth (MPKV), Rahuri, District Ahmednagar, (M.S.) during *kharif* season of year 2021-22 and 2022-23 for two consecutive years. Geographically the research farm lies between latitude 19322' 26" N and longitude 74655' 25" E, at an elevation of 602.6 ± 11m above MSL in the scarcity zone of Western Maharashtra which comes under the Western Plateau and Hilly Region of India. The soil of the experimental field was medium black *Vertic* which comes under great group *Haplustept* (Inceptisol) and clay in texture. The bulk density of the soil was 1.25 mg m^{-3} and the per cent moisture held at FC and PWP of the soil was 41.79 and 19.42 per cent, respectively. The soil was moderately alkaline in reaction with pH 8.25 and EC (0.25 dSm^{-1}). It was low in available N (181.80 kg ha^{-1}), available P was medium (15.62 kg ha^{-1}) and very high in available K (469.85 kg ha^{-1}).

The experiment was laid out in a randomized complete block design (RBD) comprised of thirteen treatments which were replicated thricely. From treatment number one to seven (T_1 – T_7), base crop (Pigeonpea) and all intercrops (Onion, Cauliflower, Greengram, Soybean, Sesame and Pearlmillet) were sown/planted as sole crops and again these all intercrops were grown with pigeonpea from treatment number eight to treatment thirteen (*viz.*, T_8 - Pigeonpea + Onion (1:8), T_9 - Pigeonpea + Cauliflower (1:3), T_{10} - Pigeonpea + Greengram (1:5), T_{11} - Pigeonpea + Soybean (1:5), T_{12} - Pigeonpea + Sesame (1:5) and T_{13} – Pigeonpea + Pearlmillet (1:5)). The seeds of pigeonpea variety Phule Rajeshwari was dibbled at 180 cm x 30 cm spacing, while intercrops were sown/planted as per row proportion decided by recommended spacing. As this trial laid out on organically certified field, all package of practices were carried out as per organic standards. The experimental field during both years manured with fully decomposed farm yard manure (FYM), neem cake (NC) and vermicompost (VC) ($^1/_3$ of each) to fulfil the requirement of recommended dose of nitrogen (RDN). Protected irrigation was given during long dry spell period.

Protein content (%) in pigeonpea grain was determined by the nitrogen content in pigeonpea grain multiplied by 6.25.

$$\text{Protein yield} = \frac{\text{Protein content (\%) x Grain yield (kg ha}^{-1}\text{)}}{100}$$

Nutrient uptake by pigeonpea grain and stalk was determined by following procedure:

Dry matter = Dry weight / fresh weight x 100

Dry matter yield = Dry matter x Fresh yield

Nutrient uptake = Percent of nutrient concentration in sample x Dry matter yield

Results and Discussion

Quality parameters of pigeonpea

Nutrient (NPK) content in seed and stover of Pigeonpea

NPK content in seed (%)

The nitrogen, phosphrous and potassium content (%) in Pigeonpea seed as influenced by intercropping of different crops with Pigeonpea are presented in Table 1. The mean content of N, P_2O_5 and K_2O in seed of Pigeonpea were 3.33, 0.36 and 0.91% on pooled mean basis, respectively.

The nitrogen, phosphrous and potassium content (per cent) in seed of Pigeonpea was not influenced significantly due to intercropping of different crops with Pigeonpea. The treatment T_1 (Sole Pigeonpea) registered numerically highest nitrogen, phosphrous and potassium content in seed (3.40% N, 0.38% P_2O_5 and 0.93% K_2O on pooled analysis basis) at harvest than rest of other treatments of intercropping system. However, it was numerically followed by T_{11} - Pigeonpea + Soyebean (1:5) which recorded 3.36% N, 0.38% P_2O_5 and 0.93% K_2O at harvest during first year, second year and on pooled mean basis, respectively and it was again followed by treatment T_{10} - Pigeonpea + Greengram (1:5). Furthermore, treatment T_{13} - Pigeonpea + Pearlmillet (1:5) was recorded significantly lowest nitrogen content in seed over treatment T_1 (Sole Pigeonpea) and numerically lowest over all other intercropping systems and recorded 3.29% N, 0.33% P_2O_5 and 0.89% K_2O during year 2021, 2022 and on pooled mean basis, respectively.

NPK content in stover (%)

The nitrogen, phosphrous and potassium content (%) in stover of Pigeonpea as influenced by intercropping of different crops with Pigeonpea are showed in Table 1. The mean N, P_2O_5 and K_2O content in stover of Pigeonpea were 1.22% N, 0.16% P_2O_5 and 1.15% K_2O on pooled mean basis.

The nitrogen, phosphrous and potassium content (per cent) in stover of pigeonpea was significantly not influenced due to intercropping of different crops with Pigeonpea. The treatment T_1 (Sole Pigeonpea) was registered 1.26% N, 0.18% P_2O_5 and 1.17% K_2O content in stover at harvest on pooled analysis basis and which were found numerically highest than rest of other intercropping systems. However, treatment T_1 (Sole Pigeonpea) was numerically followed by T_{11} - Pigeonpea + Soyebean (1:5) which recorded 1.25% N, 0.17% P_2O_5 and 1.17% K_2O at harvest on pooled mean basis and it was followed by treatment T_{10} - Pigeonpea + Greengram (1:5). Moreover, treatment T_{13} - Pigeonpea + Pearlmillet (1:5) was noted significantly lowest NPK content in stover over treatment T_1 (Sole Pigeonpea) and numerically lowest over all other intercropping systems and recorded 1.19% N, 0.15% P_2O_5 and 1.14% K_2O content on pooled mean basis.

Protein Content (%)

The protein content in pigeonpea grain as influenced by intercropping of different crops with pigeonepa are presented in Table 1. The mean protein content recorded in pigeonpea grain was 20.80 per cent on pooled mean basis.

Data presented in Table 1 showed that the protein content (per cent) in pigeonpea grain was not affected statistically due to intercropping of different crops on pooled mean basis. Among different treatments of intercropping of different crops with Pigeonpea, treatment T_1 (Sole Pigeonpea) recorded numerically greater protein content (21.23%) than rest of the treatments on pooled mean basis. Whereas, treatment T_{11} - Pigeonpea + Soyebean (1:5) followed by T_{10} - Pigeonpea + Greengram (1:5) was recorded numerically maximum protein content (21.02% and 20.89% on pooled mean basis, respectively) after treatment T_1 (Sole Pigeonpea). Furthermore, treatment, T_{13} - Pigeonpea + Pearlmillet (1:5) listed numerically lowest protein content (20.54%) on pooled mean basis.

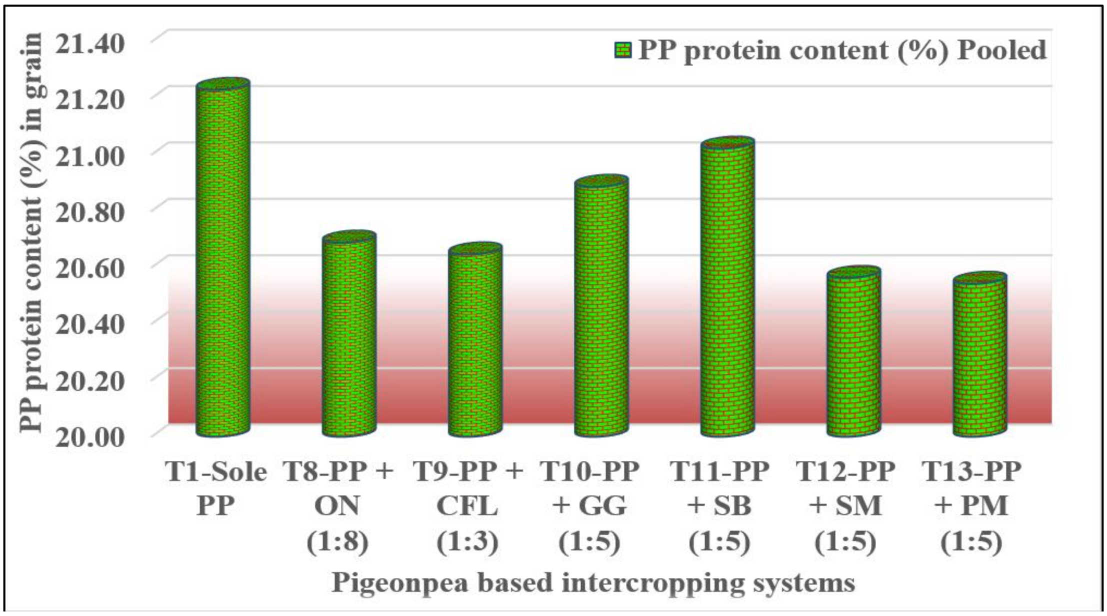
Protein Yield (kg ha^{-1})

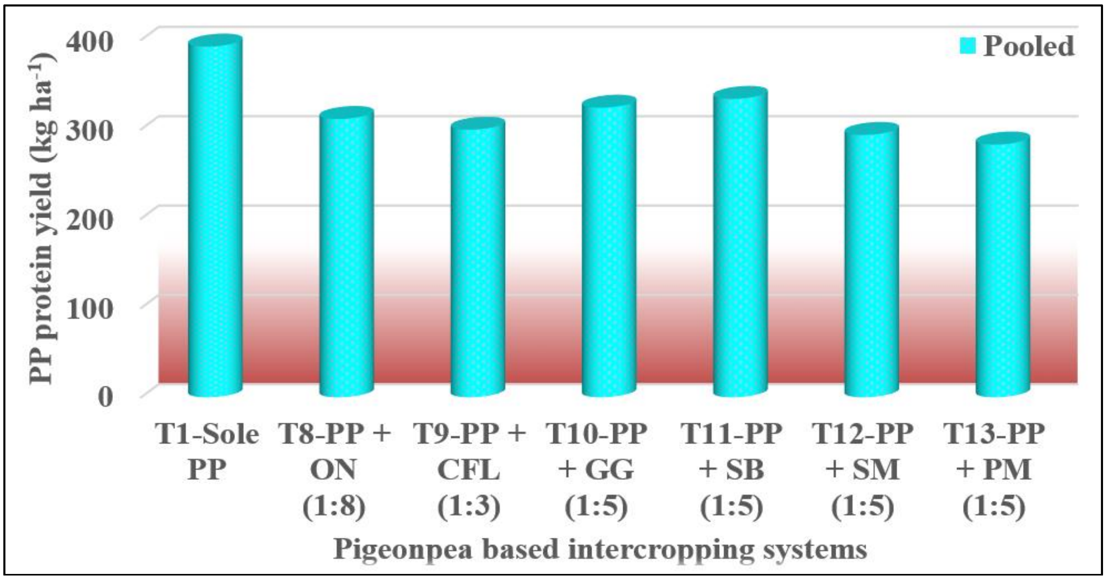
The protein yield of pigeonpea as influenced by intercropping of different crops with Pigeonepa are given in Table 1. and graphically it is depicted in Fig. The mean protein yield of pigeonpea was 319.82 kg ha^{-1} on pooled analysis basis.

The results data displayed in Table 1 observed that the protein yield of pigeonpea was affected significantly due to intercropping of different crops with pigeonepa on pooled mean basis. The treatment T_1 (Sole Pigeonpea) listed significantly higher protein yield (392.43 kg ha^{-1}) over rest of the intercropping system treatments on pooled mean basis. However, T_1 (Sole Pigeonpea) was numerically followed by T_{11} - Pigeonpea + Soyebean (1:5) and T_{10} - Pigeonpea + Greengram (1:5) and recorded 334.06 kg ha^{-1} and 324.25 kg ha^{-1} on pooled mean basis, respectively. Higher protein yield in treatment T_1 (Sole Pigeonpea), may be attributed to enhanced photosynthesis, root enlargement and improved chemical and microbial activities under favorable soil conditions. These factors provide better nutrition to plants, allowing for increased protein synthesis through amino acids as a result of enhanced nitrogen metabolism. Furthermore, treatment T_{13} - Pigeonpea + Pearlmillet (1:5) was recorded significantly minimum protein yield (282.95 kg ha^{-1}) over treatment T_1 (Sole Pigeonpea) and similarly, it was numerically minimum over all other treatments of intercropping system on pooled mean basis. These results are resembled with those narrated by Reddy *et al*., (2007) [3], Tiwari *et al*., (2011) [4] and Pal and Singh (2015) [5].

Table 1: Nitrogen, Phosphorus and Potassium content in seed and stalk/stover, Protein content in seed and Protein yield of pigeonpea at harvest as influenced by intercropping of different crops.

Treatment	Seed			Stalk/Stover			Protein content (%)	Protein yield (kg ha^{-1})
	Nitrogen content (%)	Phosphorus content (%)	Potassium content (%)	Nitrogen content (%)	Phosphorus content (%)	Potassium content (%)		
	(At harvest)			(At harvest)				
	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled	Pooled
T_1-Sole Pigeonpea	3.40	0.38	0.93	1.26	0.18	1.17	21.23	392.43
T_2-Sole Onion	-	-	-	-	-	-	-	-
T_3-Sole Cauliflower	-	-	-	-	-	-	-	-
T_4-Sole Greengram	-	-	-	-	-	-	-	-
T_5-Sole Soybean	-	-	-	-	-	-	-	-
T_6-Sole Sesame	-	-	-	-	-	-	-	-
T_7-Sole Pearlmillet	-	-	-	-	-	-	-	-
T_8-PP + Onion (1:8)	3.31	0.36	0.90	1.22	0.16	1.15	20.69	311.62
T_9-PP + Cauliflower (1:3)	3.30	0.35	0.90	1.20	0.16	1.14	20.65	299.69
T_{10}-PP + Greengram (1:5)	3.34	0.36	0.92	1.25	0.16	1.16	20.89	324.25
T_{11}-PP + Soybean (1:5)	3.36	0.38	0.93	1.25	0.17	1.17	21.02	334.06
T_{12}-PP + Sesame (1:5)	3.29	0.35	0.89	1.20	0.15	1.14	20.56	293.72
T_{13}-PP + Pearlmillet (1:5)	3.29	0.33	0.89	1.19	0.15	1.14	20.54	282.95
SE. m. (±)	0.04	0.01	0.01	0.03	0.01	0.01	0.22	7.35
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	21.46
General mean	3.33	0.36	0.91	1.22	0.16	1.15	20.80	319.82





Total Nitrogen, Phosphorus and Potassium Uptake by Grain and Stover of Pigeonpea (kg ha^{-1})

The data regarding mean total uptake of N, P_2O_5 and K_2O (kg ha^{-1}) by grain, and stover of pigeonpea crop as influenced by intercropping of different crops with pigeonepa are presented in Table 2 and graphically it is depicted in Fig. The mean total uptake of N, P_2O_5 and K_2O (kg ha^{-1}) by grain and stover of pigeonpea crop was 79.36, 84.45 and 81.91, 9.17, 10.35 and 9.76 and 45.79, 48.89 and 47.34 kg ha^{-1} during first year second year and on pooled mean basis, respectively.

The nutrient uptake is a function of the seed and stover yield and their nutrient concentrations. Therefore, the higher concentrations of N, P_2O_5 and K_2O, combined with increased seed and stover yields, resulted in an overall enhancement of the total uptake of these nutrients. The intercropping of Pearlimillet with Pigeonpea significantly reduced the uptake of nitrogen, phosphorus and potassium in pigeonpea as compared to when it was grown alone. This is primarily due to Pearlmillet's higher competitive ability for nutrients. Additionally, the taller Pearlmillet plant shaded the Pigeonpea at early stage of growth, limiting both its above-ground and below-ground growth by reducing radiation interception. When Pigeonpea was intercropped with Pearlmillet, essential resources such as nutrients, moisture and sunlight are shared with Pearlmillet being the stronger competitor. This resource competition leads to a decrease in the uptake of NPK and the overall nutrient uptake in the intercropping system.

Nitrogen Uptake by Pigeonpea (kg ha^{-1})

The nitrogen uptake by seed and stover as well as total uptake by pigeonpea crop were significantly influenced due to intercropping of different crops. The mean total uptake of nitrogen by grain and stover of pigeonpea crop was 79.36, 84.45 and 81.91 kg ha^{-1} during year 2021, 2022 and on pooled mean basis, respectively.

The total uptake of nitrogen by seed and stover (97.29, 102.73 and 100.01 kg ha^{-1} during first year, second year and on pooled mean basis, respectively) was recorded significantly highest with treatment T_1 (Sole Pigeonpea) as compared to rest of the intercropping system treatments. However, it was numerically followed by T_{11} - Pigeonpea + Soyebean (1:5) and T_{10} - Pigeonpea + Greengram (1:5) which were recorded 83.39, 89.01 and 86.20 kg ha^{-1} during year 2021, 2022 kg ha^{-1} and on pooled mean basis, respectively. While, the significantly lowest total uptake of nitrogen by grain and stover of pigeonpea was observed under treatment T_{13} - Pigeonpea + Pearlmillet (1:5) and values observed were 69.52, 73.58 and 71.55 kg ha^{-1} during first year, second year and on pooled mean basis, respectively and it was followed by treatment T_{12} - Pigeonpea + Sesame (1:5).

The increase in nitrogen uptake may be attributed to the application of FYM, vermicompost and neem cake. This can be attributed to the favorable effects of organic manure on higher seed and stover yields, as well as the increased nitrogen content in seeds and stalks, leading to greater removal of nitrogen. Instead of that, higher uptake of nitrogen by Sole Pigeonpea might be due there was no competition of any other crop with it for nutrients. These findings are corroborate the report of Kumawat *et al*., (2015) [1] and s *et al*., (2022) [2].

Phosphorus Uptake by Pigeonpea (kg ha^{-1})

The total phosphorus uptake by seed and stover of pigeonpea crop were significantly influenced due to intercropping of different crops. The mean total uptake of phosphorus by grain and stover was 9.17, 10.35 and 9.76 kg ha^{-1} during year 2021, 2022 and on pooled mean basis, respectively.

The total uptake of phosphorus by seed and stover of pigeonpea (11.72, 13.33 and 12.52 kg ha^{-1} during first year, second year and on pooled mean basis, respectively) was recorded significantly highest with treatment T_1 (Sole Pigeonpea) as compared to rest of the intercropping system treatments. However, it was numerically followed by T_{11} - Pigeonpea + Soyebean (1:5) and T_{10} - Pigeonpea + Greengram (1:5) which were recorded 9.86, 11.26 and 10.56 kg ha^{-1} and 9.02, 10.37 and 9.69 kg ha^{-1} during year 2021, 2022 and on pooled mean basis, respectively. While, the significantly lowest total uptake of phosphorus was observed under treatment T_{13} - Pigeonpea + Pearlmillet (1:5) and uptake values recorded were 7.47, 8.58 and 8.03 kg ha^{-1} during first year, second year and on pooled mean basis, respectively and it was followed by treatment T_{12} - Pigeonpea + Sesame (1:5).

Higher uptake of phosphorus by Sole Pigeonpea might be due to maximum dry matter yield and the absence of competition from intercrops particularly, Pearlmillet, Sesame and Cauliflower for nutrients. The phosphorus content combinedly in seeds and stover, along with the enhanced yields (Table 1), may have resulted in increased phosphorus uptake due to the application of organic manure. This can be attributed to the beneficial effects of organic manure in promoting the formation of lateral and fibrous roots, which enhance root proliferation and expand the nutrient-absorbing surface area. Consequently, the improved root absorption capacity, coupled with the increased availability of P_2O_5, likely contributed to the higher phosphorus uptake by the plants. The finding is in analogous with those reported by Kumawat *et al*., (2015) [1] and Bhadu *et al*., (2022) [2].

Potassium Uptake by Pigeonpea (kg ha^{-1})

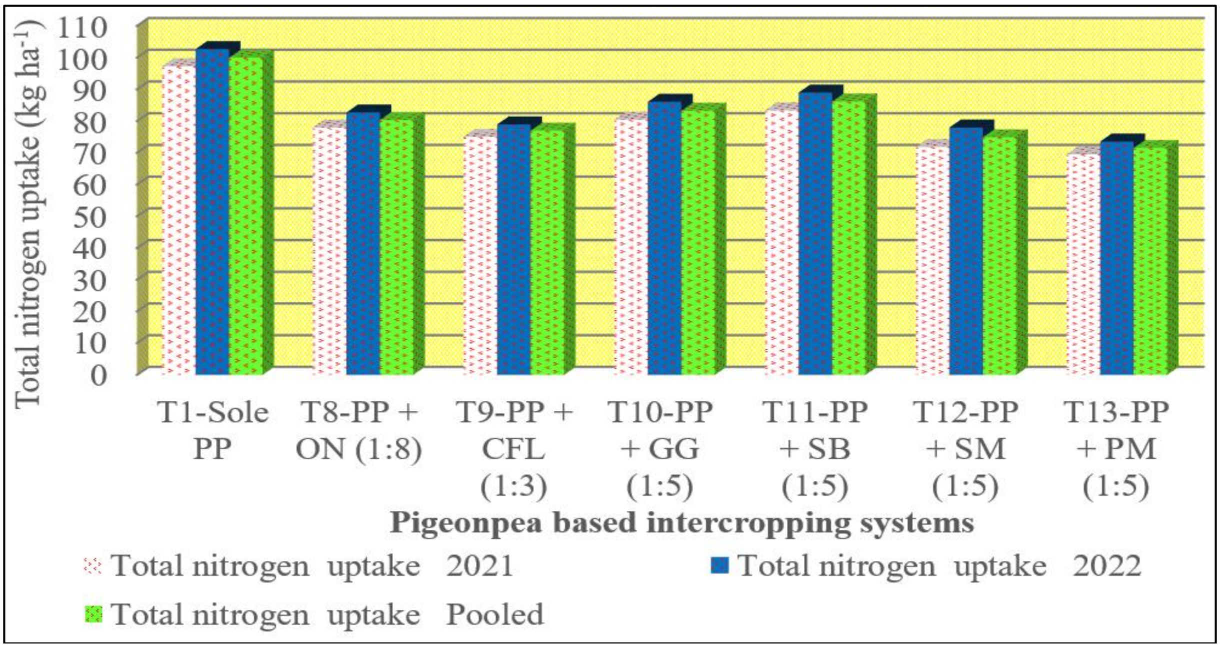
The total uptake of potassium by seed and stover of pigeonpea crop were significantly influenced due to intercropping of different crops. The mean uptake of potassium by grain, stover and total uptake was 45.79, 48.89 and 47.34 kg ha^{-1} during year 2021, 2022 and on pooled mean basis, respectively.

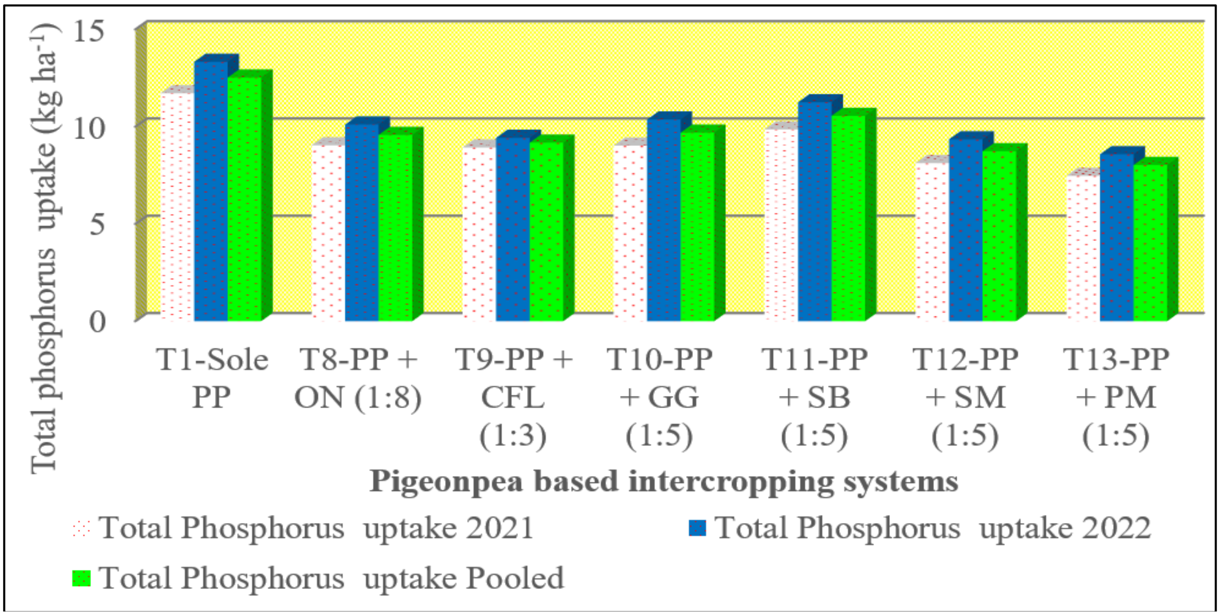
The total uptake of potassium by seed and stover of pigeonpea (55.01, 58.90 and 56.95 kg ha^{-1} during first year, second year and on pooled mean basis, respectively) was recorded significantly highest with treatment T_1 (Sole Pigeonpea) as compared to rest of the intercropping system treatments. However, it was numerically followed by T_{11} - Pigeonpea + Soyebean (1:5) and T_{10} - Pigeonpea + Greengram (1:5) which were recorded 48.10, 51.87 and 49.99 kg ha^{-1} and 46.24, 49.44 and 47.84 kg ha^{-1} during year 2021, 2022 and on pooled mean basis, respectively. While, the significantly lowest total uptake of potassium was observed under treatment T_{13} - Pigeonpea + Pearlmillet (1:5) and uptake values recorded were 40.87, 42.93 and 41.90 kg ha^{-1} during first year, second year and on pooled mean basis, respectively and it was followed by treatment T_{12} - Pigeonpea + Sesame (1:5).

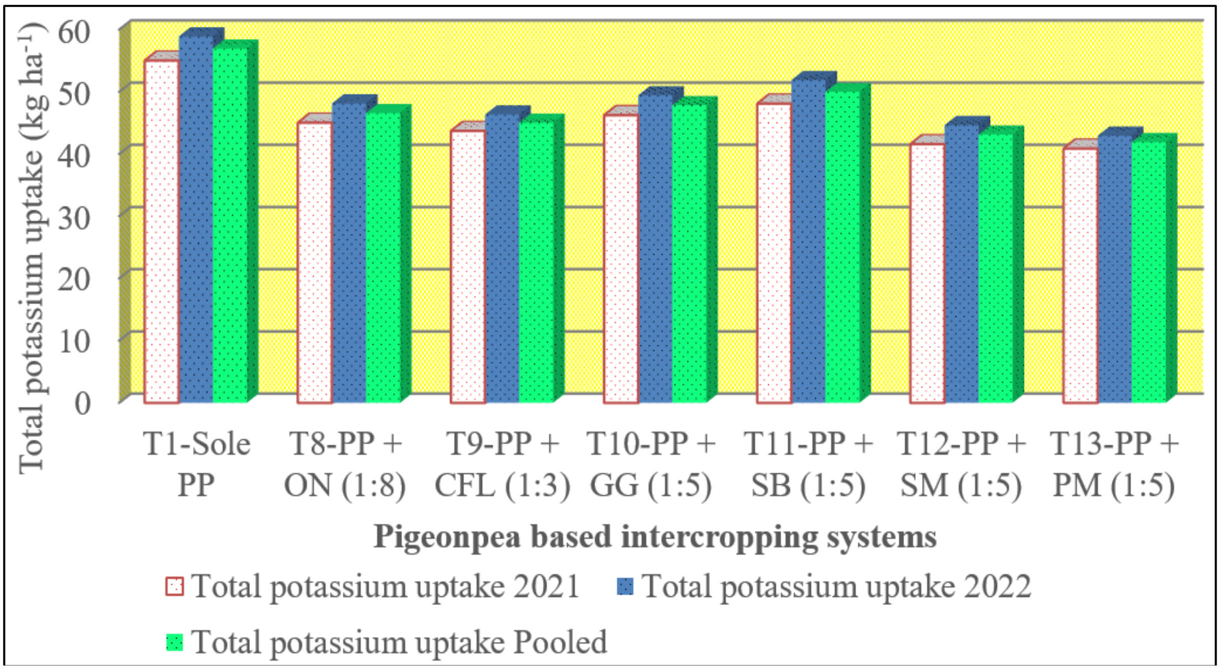
The organic manures increased the concentration of nutrients in soil solution which increased the supply of potassium and also favors root development making them more efficient in absorbing nutrient. Potassium uptake could be attributed due to additive effect of increased seed and stalk. The result substantiated the finding of Kumawat *et al*., (2015) [1] and Bhadu *et al*., (2022) [2].

Table 2: Total Nitrogen, Phosphorus and Potassium uptake by grain and stover of pigeonpea at harvest as influenced by intercropping of different crops during 2021-22 and 2022-23.

Treatment	Total nitrogen uptake (kg ha^{-1})			Total phosphorus uptake (kg ha^{-1})			Total potassium uptake (kg ha^{-1})		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T_1-Sole Pigeonpea	97.29	102.73	100.01	11.72	13.33	12.52	55.01	58.90	56.95
T_2-Sole Onion	-	-	-	-	-	-	-	-	-
T_3-Sole Cauliflower	-	-	-	-	-	-	-	-	-
T_4-Sole Greengram	-	-	-	-	-	-	-	-	-
T_5-Sole Soybean	-	-	-	-	-	-	-	-	-
T_6-Sole Sesame	-	-	-	-	-	-	-	-	-
T_7-Sole Pearlmillet	-	-	-	-	-	-	-	-	-
T_8-PP + Onion (1:8)	77.99	82.75	80.37	9.04	10.11	9.58	45.03	48.12	46.58
T_9-PP + Cauliflower (1:3)	75.04	78.96	77.00	8.93	9.43	9.18	43.71	46.34	45.02
T_{10}-PP + Greengram (1:5)	80.47	86.12	83.30	9.02	10.37	9.69	46.24	49.44	47.84
T_{11}-PP + Soybean (1:5)	83.39	89.01	86.20	9.86	11.26	10.56	48.10	51.87	49.99
T_{12}-PP + Sesame (1:5)	71.84	78.00	74.92	8.13	9.35	8.74	41.58	44.64	43.11
T_{13}-PP + Pearlmillet (1:5)	69.52	73.58	71.55	7.47	8.58	8.03	40.87	42.93	41.90
SE. m. (±)	2.60	2.99	1.98	0.36	0.62	0.36	1.41	1.58	1.06
C.D. at 5%	8.03	9.21	5.79	1.11	1.91	1.05	4.33	4.87	3.09
General mean	79.36	84.45	81.91	9.17	10.35	9.76	45.79	48.89	47.34







Conclusion

The Sole Pigeonpea (T_1) consistently outperformed treatment with respect to total uptake of nitrogen, phosphorus and potassium by grain and stalk, however it was numerically followed by T_{11} and T_{10} intercropping system treatment. Treatment T_1 also showed numerically higher nutrient content (NPK), protein content and protein yield and it was followed by T_{11} and T_{10}. Intercropping of pigeonpea with legumes like Soybean (T_{11}) and Greengram (T_{10}) at 1:5 sowing proportion showed better results compared to intercropping with non-leguminous crops like pearlmillet (T_{13}) and sesame (T_{12}).

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