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**Research Paper**

# Productivity and profitability of pigeonpea (*Cajanus cajan*)-based intercropping systems under diverse nutrient management practices in rainfed condition

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## ABSTRACT

A field experiment was conducted at Agronomy Research Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, on silty loam soil during the rainy (*kharif)* seasons of 2014–2018, to study the productivity and profitability of pigeonpea [*Cajanus cajan* (L.) Millsp.]-based intercropping under divers nutrient management in rainfed condition. The experiment consisted of 3 intercropping, viz. $C_1$, pigeonpea sole; $C_2$, pigeonpea + blackgram [*Vigna mungo* (L.) Hepper]; and $C_3$, pigeonpea + maize (*Zea mays* L.); and 4 practices nutrient management, viz. $N_1$, recommended dose of fertilizer (RDF); $N_2$, RDF + phosphate-solubilizing bacteria (PSB) + *Rhizobium;* $N_3$, RDF + PSB + *Rhizobium* + FYM @ 3 t/ha; and $N_4$, RDF + PSB + *Rhizobium* + FYM @ 3 t/ha + *Harit-Varda*n @ 5 kg/ha. The experiment was laid out in factorial randomized-block design with 3 replications**.** Results revealed that, pigeonpea + blackgram system, showed higher yield of pigeonpea (1.71 t/ha), pigeonpea-equivalent yield (2.29 t/ha), rain water-use efficiency, (5.84 kg/ha-mm), organic carbon (0.33 %), available N (164.92 kg/ha), P (18.74 kg/ha), K (245.08 kg/ha) and S (11.30 ppm) and microbial population in cfu/g dry soil, and dehydrogenase activity (17.49 µg TPF/g/h), net returns (61.15 × $10^3$ ₹/ha), benefit: cost ratio (2.06) than pigeonpea sole and pigeonpea + maize systems. The combined application of RDF + *Rhizobium* + PSB + FYM @ 3 t/ha + Harit-Vardan @ 5 kg/ha proved effective and resulted in significantly higher pigeonpea grain yield (1.65 t/ha), pigeonpea-equivalent yield (2.16 t/ha), rain water-use efficiency (4.94 kg/ha-mm), organic carbon (0.34%), available N (161.59 kg/ha), P (18.37 kg/ha), K (241.96 kg/ha) and S (11.92 ppm) and microbial population and dehydrogenase activity (15.56 µg TPF/g/h) and net returns as compared to RDF alone. However, higher net returns (55.4 × $10^3$ ₹/ha) per rupee investment were recorded in combined application of RDF + *Rhizobium* + PSB + FYM @ 3 t/ha + Harit-Vardan @ 5 kg/ha. The pigeonpea + blackgram intercropping and combined application of FYM @ 3 t/ha along with RDF + *Rhizobium* + PSB improved the organic carbon and increased available N, P and K content in the soil over initial soil value.

***Key worlds***: Dehydrogenase, INM, Pigeonpea intercropping, Rainfed, Microbial population

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an important climate-resilient pulse crop of rainfed condition because of its ability to produce economic yield under limited moisture conditions. Water stress (drought and waterlogging), non-availability of suitable varieties, inadequate transfer of technology, problems of weeds, insects-pests and diseases are the major factors for the reduction of yield pigeonpea (IIPR, 2010). Pigeonpea is a tall growing, wide-spaced crop with a deep root-system which can accommodate short-duration cereals and pulses having a shallow root-system and utilize the benefit of initial slow growth of pigeonpea (Das *et al.,* 2016). Cultivation of fast-growing crops like blackgram [*Vigna mungo* (L.) Hepper], cowpea [*Vigna unguiculata* (L.) walp.] or maize (*Zea mays* L.) as intercrop can potentially boost the farm productivity and economic sustainability (Yadav *et al*., 2021). The low yield of pigeonpea is not only owing its cultivation in sub-marginal lands, but also due to poor agronomical management (Babu *et al.,* 2016). It is generally due to soil-moisture deficit during critical growth stages, such as flowering and pod development which results in a significant reduction in

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grain yield (Sharma *et al.,* 2012). Use of biofertilizers such as biological nitrogen fixing and phosphate-solubilizing micro-organisms is also gaining importance since biofertilizers are cost-effective, eco-friendly, and renewable sources of plant nutrients to supplement chemical fertilizers. Organic manures and biofertilizers (*Rhizobium* + phosphate-solubilizing bacteria) which have been reported to be beneficial in augmenting the yield of grain legumes. Fertilizers use continued to play a key role in augmenting higher crop productivity, but reckless use deteriorates soil health, energy-conserving ecosystem and economics. It has been realized that not only chemical fertilizers but also organic manures in conjunction with biofertilizers will sustain and maintain the soil productivity. Therefore, it is needed to compare various organic as well as biological sources of nutrients with chemical fertilizers in order to find out the most effective combination. *Harit-Vardan* protects crop plants under water-stress conditions by making the regular supply of moisture and nutrient throughout the crop season and increasing water-and fertilizer-use efficiency. It makes possible the significant enhancement in quality of crop produce, saving of 50 to 60 % irrigation water and 30 to 35% fertilizers and decrease in cost of cultivation. Hence an experiment was conducted to study productivity and profitability of pigeopea-based intercropping systems under diverse nutrient-management systems in rainfed condition.

## MATERIALS AND METHODS

A field experiment was conducted during 2014–2018 on silty loam soil, slight alkaline having *p*H 7.86. It was low in organic carbon (0.29%), available nitrogen (155.96 kg/ha), and phosphorus (13.22 kg/ha) and medium in potassium (314.63 kg/ha). The experiment consisted of 3 intercropping, viz. $C_1$, pigeonpea sole; $C_2$, pigeonpea + blackgram; and $C_3$, pigeonpea + maize, and 4 nutrient management, viz. $N_1$, recommended dose of fertilizer; $N_2$, RDF + phosphate-solubilizing bacteria (PSB) + *Rhizobium;* $N_3$, RDF + PSB + *Rhizobium* + FYM @ 3 t/ha; and $N_4$, RDF + PSB + *Rhizobium* + FYM @ 3 t/ha + *Harit-Vardan* @ 5 kg/ha. The experiment was laid out in factorial randomized-block design with 3 replications. Pigeonpea 'Narendra Arhar 1', blackgram 'Narendra Urd 1' and maize 'MM 1107' were sown with a seed rate of 16 kg/ha, 20 kg/ha and 25 kg/ha, respectively, during the second fortnight of June every year. The recommended dose of fertilizers (N, P, K kg/ha) was given to each crops (pigeonpea 20 : 40 : 0 and blackgram 20 : 40 : 0 and maize 60 : 40 : 30) individually. Full doses of nitrogen, phosphorus and potassium were applied at the time of sowing in pigeonpea and blackgram. However, in maize, half of the nitrogen, full doses of phosphorus and potassium were applied at the time of sowing and remaining nitrogen was top-dressed in 2 equal splits, i.e. one-fourth at 40 days and one-fourth at teaseling stage of the crop. In order to maintain the optimum plant population, thinning and gap-filling was done in each crop 10 days after sowing. All the crops were grown as per the recommended package of practices of the region. The productive capacity of the tested systems was measured in terms of pigeonpea-equivalent yield (PEY) at a price scale. The Government of India declared minimum support prices were used for all the crops.

Post-harvest soil samples were drawn at 15 cm soil depth and collected samples were air-dried, and passed through 2-mm sieve. Processed sample was used for laboratory analysis. Organic carbon was assessed by wet-digestion method (Walkley and Black, 1934), available N by alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus (P) by 0.5 m $NaHCO_3$-extractable Olsen's colorimetric method (Olsen's 1954), available potassium (K) by neutral normal ammonium acetate method (Jackson, 1973) and S by turbidimetric method (Chesnin and Yien, 1950). The population of bacteria, actinomycetes and fungi in soil was determined by cereal dilution pour plate using Thornton's medium for bacteria Thornton's (1922), Ken Knight and Munaier's medium for actinomycetes Subba Rao (1986) and Martin's Rose-Bengal streptomycin agar medium for fungi Martin (1950), respectively, soil Dehydrogenase activity (2, 3, 5 triphenyl tetrazolium chloride) was determined a method suggested by Ross (1970).

## RESULTS AND DISCUSSION

The maximum grain yield of pigeonpea was recorded under pigeonpea + blackgram intercropping system which was significantly higher than pigeonpea sole and pigeonpea + maize systems (Table 1). Sizable reduction in pigeonpea yield was recorded under pigeonpea + maize intercropping due to more competition between maize and pigeonpea for space, nutrient, moisture and solar energy during at growth period. Similarly, higher pigeonpea-equivalent yield was recorded with pigeonpea + blackgram system, which was significantly higher than pigeonpea sole and pigeonpea + maize intercropping system (Table 1). It might be due to higher grain yield of pigeonpea coupled with higher market price of component crops under the same intercropping system because of bonus yield of component in intercropping system. Crop-equivalent yields of the intercropping systems involving blackgram and maize with pigeonpea were greater than sole, indicating greater biological efficiency in utilization of land, space and time by intercrops and thereby yield advantages over the respective sole crops. This might be because of the absence of competition between main crop and intercrop for growth resources such as nutrients, moisture, solar radiation and shorter duration

**Table 1.** Effect of diverse nutrient management practices on grain yield of components crops and pigeonpea-equivalent yield in pigeonpea-based intercropping system (pooled mean of 4 years)

| Treatment | Grain yield (t/ha) | | | Pigeonpea-equivalent yield (t/ha) | RWUE (kg/ha-mm) |
|---|---|---|---|---|---|
| | Pigeonpea | Blackgram | Maize | | |
| *Inter-cropping system* | | | | | |
| Pigeonpea sole | 1.55 | – | – | 1.55 | 3.42 |
| Pigeonpea + blackgram | 1.71 | 0.61 | | 2.29 | 5.87 |
| Pigeonpea + maize | 1.20 | – | 2.57 | 1.92 | 4.20 |
| SEm± | 0.37 | – | – | 0.49 | |
| CD (P=0.05) | 1.14 | – | – | 1.45 | – |
| *Nutrient-management practices* | | | | | |
| RDF | 1.25 | 0.47 | 2.2 | 1.41 | 3.59 |
| RDF + *Rhizobium* + phosphate-solubilizing bacteria | 1.41 | 0.57 | 2.41 | 1.82 | 4.11 |
| RDF + *Rhizobium* + farmyard manure @ 3 t/ha | 1.60 | 0.67 | 2.82 | 2.08 | 4.69 |
| RDF + *rhizobium* + farmyard manure @ 3 t/ha + *Harit-Vardan* @ 5 kg/ha | 1.68 | 0.71 | 2.88 | 2.16 | 4.94 |
| SEm± | 0.16 | | | 0.18 | |
| CD (P=0.05) | 0.45 | | | 0.56 | |

FYM, Farm yard manure; RWUE, rain water-use efficiency

nature of blackgram. Our results confirm the findings of Meena *et al.,* (2009). Maximum rain water-use efficiency was recorded with pigeonpea + blackgram intercropping system as compared to pigeonpea sole and pigeonpea + maize.

In nutrient management system, the maximum grain yield of pigeonpea and pigeonpea equivalent yield were recorded under RDF + *Rhizobium* + PSB + FYM @ 3 t/ha + *Harit-Vardan* @ 5 kg/ha as compared to RDF and RDF + *Rhizobium* + PSB, while at par with RDF + *Rhizobium* + PSB + FYM @ 3 t/ha (Table 1). The increase in yield might be due to the beneficial effect of combined use of organics (FYM @ 3 t/ha with *Harit-Vardan* @ 5 kg/ha) and balanced inorganic fertilization + seed inoculation of biofertilizer over RDF alone. These results confirm the findings of Kumar and Gautam (2004) and Saritha *et al.* (2012). This might have resulted in profuse shoot and root growth, and thereby activating greater absorption of these nutrients from soil, and improved grain yield (Goud and Kale, 2010). Similar results were reported by Pal *et al.*, (2016). Similarly, addition of FYM @ 3 t/ha along with RDF + PSB + *Rhizobium* culture also significantly increased the RWUE over rest of the nutrient-management options, while at par with addition of *Harit-Vardan* and biofertilizer during 2014 to 2018. Rain water-use efficiency also increased in integration of nutrients through inorganic and organic than inorganic alone. The increased in rain water use efficiency (RWUE) under these treatments was achieved due to increase in total grain production per unit of water used. Similar results were reputed by Sharma and Guled (2011).

Maximum of nitrogen, phosphorus, potassium and sulphur availability was recorded with pigeonpea + blackgram system as compared to pigeonpea sole and pigeonpea + maize intercropping system (Table 2). It was noted that when maize was grown as an intercrop with pigeonpea, significant reduction took place in the fertility status of these nutrients. Here, it may be pointed out that, maize is a nutrient exhaustive crop which removed higher amounts of N, P, K and micronutrients resulted in poor fertility status of soil, even lower than initial status of available N, P and K. on cautery the addition of organic matter through huge leaf fall, roots, nodules and plant residue decomposition in system (Shrinivasulu *et al.*, 2000). Intercropping of a short duration legume with pigeonpea improves organic carbon and available nitrogen and reduces the depletion of soil phosphorus and potassium (Mercy and Prasad, 1989). The lower values of organic carbon under pigeonpea + maize intercropping system compared to sole pigeonpea during 2014 to 2018 might be due to reduced number of nodules/unit area, low $N_2$ fixation by pigeonpea crop because of root allelopathy and more absorption of nutrients by component cereal crop.

In nutrient management practices, the maximum availability of organic carbon, nitrogen, phosphorus, potassium and sulphur was found with the treatment $N_4$, RDF + *Rhizobium* + PSB + FYM @ 3 t/ha + *Harit-Vardan* @ 5 kg/ha, being significantly higher than to recommanded dose of fertilizers and RDF + *Rhizobium* + phosphate-solubilizing bacteria while remained at par with RDF +

**Table 2.** Effect of cropping systems and nutrient management practice on soil organic carbon, available nitrogen, phosphorus, potassium and sulphur in soil (pooled mean of 4 years)

| Treatment | Organic carbon (%) | Available N (kg/ha) | Available P (kg/ha) | Available K (kg/ha) | Available S (ppm) |
|---|---|---|---|---|---|
| *Intercropping system* | | | | | |
| Pigeonpea sole | 0.31 | 159.17 | 17.17 | 242.11 | 10.92 |
| Pigeonpea + blackgram | 0.33 | 164.52 | 18.78 | 245.08 | 11.30 |
| Pigeonpea + maize | 0.32 | 150.89 | 16.25 | 233.83 | 9.45 |
| SEm± | 0.01 | 1.43 | 0.50 | 3.79 | 1.98 |
| CD (P=0.05) | NS | 4.23 | 1.53 | NS | NS |
| *Nutrient management practices* | | | | | |
| RDF | 0.29 | 153.46 | 15.74 | 236.89 | 9.82 |
| RDF + *Rhizobium* + phosphate-solubilizing bacteria | 0.30 | 156.20 | 17.25 | 238.20 | 10.91 |
| RDF + *Rhizobium* + farmyard manure @ 3 t/ha | 0.33 | 161.00 | 18.23 | 241.22 | 11.34 |
| RDF + *Rhizobium* + farmyard manure @ 3 t/ha + *Harit-Vardan* @ 5 kg/ha | 0.34 | 161.59 | 18.37 | 241.96 | 11.92 |
| SEm± | 0.01 | 1.8 | 0.56 | 2.45 | 0.35 |
| CD (P=0.05) | 0.03 | 5.10 | 1.74 | 7.31 | 1.02 |

RDF, recommended dose of fertilizer

*Rhizobium* + farmyard manure @ 3 t/ha (Table 2). Increase in the availability of N in soil with FYM might be due to improve the physico chemical and biological properties of soil (Ramesh *et al*., 2006). It is evident that, the use of FYM resulted in an increase in the available P content in soil. This might be because of the production of organic acids during the process of decomposition of FYM that led to mineralization of the fixed P. in present study the K availability was also slightly increased in FYM treated plots.

Intercropping of pigeonpea + blackgram maintained significantly higher microbial population (bacteria, actinomycetes and fungi Cfu $10^6$/g dry soil) than pigeonpea sole and pigeonpea + maize intercropping (Table 3). This is because of decomposing the pulses residue after picking the pods that provide carbon to the soil microbes resulting

**Table 3.** Effect of cropping systems and nutrient management on soil microbial population after harvesting of crops (pooled mean of 4 years)

| Treatment | Viable counts (Cfu/g dry soil) | | | Dehydrogenase activity (µg TPF/g/h) |
|---|---|---|---|---|
| | Bacteria ($\times 10^6$) | Actinomycetes ($\times 10^4$) | Fungi ($\times 10^3$) | |
| *Inter-cropping system* | | | | |
| Pigeonpea sole | 11.34 | 7.30 | 5.57 | 15.46 |
| Pigeonpea + blackgram | 11.72 | 7.67 | 6.22 | 17.49 |
| Pigeonpea + maize | 10.17 | 6.41 | 5.08 | 11.54 |
| SEm± | 0.18 | 0.16 | 0.13 | 0.15 |
| CD (P=0.05) | 0.48 | 0.47 | 0.39 | 0.43 |
| *Nutrient management practices* | | | | |
| RDF | 10.06 | 6.07 | 4.74 | 13.15 |
| RDF + *Rhizobium* + phosphate-solubilizing bacteria | 10.67 | 6.76 | 5.58 | 14.07 |
| RDF + *Rhizobium* + farmyard manure @ 3 t/ha | 11.65 | 7.77 | 6.11 | 15.11 |
| RDF + *Rhizobium* + farmyard manure @ 3 t/ha + *Harit-Vardan* @ 5 kg/ha | 11.89 | 7.89 | 6.44 | 15.56 |
| SEm± | 0.18 | 0.19 | 0.15 | 0.19 |
| CD (P=0.05) | 0.53 | 0.55 | 0.45 | 0.56 |

RDF, recommended dose of fertilizer

in increased microbial population (Geethakumari and Shivashankar, 1991). The application of RDF + PSB + *Rhizobium* + FYM @ 3 t/ha + *Harit-Vardan* @ 5 kg/ha resulted in the maximum microbial population such as bacteria, actinomyceties and fungi as compared to the other treatments. There was increase in population of bacteria 6.06, 15.81 and 18.89%, actinomyceites 11.37, 28.21 and 29.98% and fungi 17.72, 28.90 and 35.86%, respectively, as compared to RDF alone. This might be owing to availability of more nutrients for growth of rhizospheric microbial population and key role of phosphorus solubilizing bacteria, *Rhizobium*, FYM and *Harit-Vardan* which could exhibit both direct and indirect effects in increasing microbial population in soil. The incorporation of FYM, *Harit-Vardan* with biofertilizer increased the soil microbial biomass than the chemical fertilizers. Better plant growth also contributes to higher microbial biomass as reported by Manna and Ganguly (2001).

Pigeonpea + blackgram intercropping system showed the highest dehydrogenase activity in soil, which was significantly higher than pigeonpea sole and pigeonpea + maize intercropping system (Table 3). Dehydrogenase activity in pigeonpea + blackgram was higher than pigeonpea sole (13.14%) and pigeonpea + maize (51.56%) intercropping system (Table 3). This is because of decomposing the blackgram residue after pod picking that provide carbon to the soil microbes resulting increased microbial population (Geethakumari and Shivashankar, 1991). The application of RDF + PSB + *Rhizobium* + FYM @ 3 t/ha + *Harit-Vardan* @ 5 kg/ha also recorded significantly higher dehydrogenease activity in soil, although it was statically at par with the application of RDF + PSB + *Rhizobium* + FYM @ 3 t/ha treatment. The positive effect of FYM and *Harit-Vardan* on dehydrogenease activity might be due to higher availability of carbon substrate in soil. As a dehydrogenase activity is influenced by changes in soil organic carbon, as the higher level of organic carbon stimulated microbial activity (Aon and Colaneri, 2001).

Maximum net returns ($61.15 \times 10^3$ ₹/ha) and benefit: cost ratio (2.06) were recorded under pigeonpea + blackgram intercropping system than pigeonpea sole and pigeonpea + maize (Table 4). Among the nutrient management options, the highest net returns ($55.40 \times 10^3$ ₹/ha) and benefit: cost ratio (1.83) were observed with $N_4$ (RDF + *Rhizobium* + PSB + FYM @ 3 t/ha + Harit-Vardan @ 5 kg/ha) followed by (RDF + *Rhizobium* + farmyard manure @ 3 t/ha), (RDF + *Rhizobium* + phosphate-solubilizing bacteria and (RDF + *Rhizobium* + PSB + FYM @ 3 t/ha). Similar results were also reported by Rajkhowa *et al*. (2002) in greengram and Sharma (2009) in pigeonpea.

Thus, it may be concluded that cultivation of pigeonpea + blackgram intercropping along RDF + FYM @ 3 t/ha and *Harit-vardan* @ 5 kg/ha can be a feasible option for boosting the pigeonpea productivity in rainfed condition besides improving the soil health.

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**Table 4.** Economics of pigeonpea-based intercropping system under diverse nutrient management practices (pooled mean of 4 years)

| Treatment | Cost of cultivation ($\times 10^3$ ₹/ha) | Gross returns ($\times 10^3$ ₹/ha) | Net returns ($\times 10^3$ ₹/ha) | Benefit: cost ratio |
|---|---|---|---|---|
| *Inter-cropping system* | | | | |
| Pigeonpea sole | 24.35 | 60.32 | 35.88 | 1.48 |
| Pigeonpea + blackgram | 29.74 | 90.89 | 61.15 | 2.06 |
| Pigeonpea + maize | 32.72 | 75.86 | 43.13 | 1.32 |
| *Nutrient-management practices* | | | | |
| RDF | 27.55 | 62.55 | 35.00 | 1.27 |
| RDF + *Rhizobium* + PSB | 27.71 | 72.14 | 44.43 | 1.60 |
| RDF + *Rhizobium* + PSB + FYM @ 3 t/ha | 29.93 | 82.22 | 52.28 | 1.75 |
| RDF + *Rhizobium* + PSB + FYM @ 3 t/ha + *Harit-Vardan* @ 5 kg/ha | 30.34 | 85.74 | 55.40 | 1.83 |

RDF, recommended dose of fertilizer; PSB, phosphate-solubilizing bacteria; FYM, farmyard manure

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