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Integrated nutrition management in pigeon pea intercropping systems for enhancing production and productivity in sustainable manner– A review

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Abstract: India is the largest producer and consumer of pulses in the world accounting for about 29 per cent of the world area and 19 per cent of the world's production. In order to achieve self-sufficiency in pulses, the projected requirement by the year 2025 is estimated at 27.5 MT. To meet this requirement, the productivity needs to be enhanced to 1000 kg/ha, and an additional area of about 3-4 Mha has to be brought under pulses besides reducing post-harvest losses. This uphill task has to be accomplished under more severe production constraints, especially abiotic stresses, abrupt climatic changes, emergence of new species/ strains of insect-pests and diseases, and increasing deficiency of secondary and micronutrients in the soil. This requires a two-pronged proactive strategy, i.e. improving per unit productivity and reducing cost of production. The yield levels of pulses have remained low and stagnant, also area and total production. Among the pulses pigeon pea is second most important grain-legumes and major constraints in pigeon pea production is mostly grown in grown on marginal lands under rainfed agriculture and without nutrient management, hence are prone to abiotic stresses. Therefore it is essential for higher production and productivity of pigeon pea, use of high yielding varieties which suitable for intercrop as well as sole cropping system with best nutrient management practices.

Keywords: Intercrop, Nutrient management practices, Pigeon pea, Productivity

INTRODUCTION

India being the largest producer 17.35 MT and processor of pulses in the world also imports 4.58 MT annually on an average to meet its ever increasing consumption needs of 22 MT. According to Indian Institute of Pulses Research's Vision document, India's population is expected to touch 1.68 billion by 2030 and the pulse requirement for the year 2030 is projected at 32 million tons with anticipated required annual growth rate of 4.2%. Among the pulses pigeon pea (*Cajanus cajan* (L.) Millsp.) is the second most important *kharif* grain legume after chickpea in India grown predominantly under rainfed conditions. It occupies an area of about 3.90 m ha with a total production of 3.17 MT with an average productivity of 813 kg/ha (Tiwari, 2016). Pigeon pea is a popular pulse crop with Indian farmers especially in view of their suitability under dryland conditions and their adoptability for pure as well as mixed/intercropping system. The low yield of pigeon pea is not only due to its cultivation on sub-marginal lands, but also because of inadequate and imbalance fertilization as well as continuous use of inorganic fertilizers which decreased the productivity, sustainability, soil health and finally affecting environment (Singh, 2007). Intensive agriculture using exhaustive high yielding varieties of crops had led to heavy withdrawal of nutrients from the soil during past few years and fertilizer consumption remained much below in comparison to removal in India. This gap between nutrient removal and supply cannot be bridged by fertilizer alone. It can only be achieved by integrated nutrient approach. To avoid negative environmental effects by fertilizer application, eco-friendly management practices can be adopted at farm level. These practices include efficient recycling of nutrients involving crop residues and waste products on the farm and proper adjustment of fertilizer doses according to requirement. Development and application of such a system appears to be an alternative to maintain sustainable agricultural system (Dijk and Pal, 1995). Adequate manuring not only improves the crop yield but also sustains the soil health and productivity. Moreover, chemical fertilizers are becoming costlier input in agriculture. Therefore, it is right time to evaluate the feasibility and efficiency of organic waste not only for improving and build up of soil fertility but also to increase efficiency of chemical fertilizer.

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Integration of chemical fertilizer with organic manures has been found to be quite promising not only in maintaining higher productivity but also in greater stability to crop production. Therefore, integration of inorganic, organic and biofertilizers are essential in realizing the higher yield and reducing cost of cultivation of pigeon pea. The work of many researchers done and discussed here in respect to integrated nutrient management practice may play significant role in enhancing production and productivity of pigeon pea in a sustainable manner as well as soil health.

Effect of integrated nutrient management on growth characters

Generally fertilizers are applied to a crop cultivar with a view to realize maximum yields within its potential. Like other field crops, pigeon pea also requires essential elements *viz*., nitrogen, phosphors, potassium, sulphur and zinc with the integration of organic manures and biofertilizers just to provide balanced nutrient and enhancing the productivity and profitability of crop.

Kene *et al.* (1990) at Nagpur reported that application of 37.5 kg N + 75 kg P_2O_5 + 20 kg K_2O + 10 kg $ZnSO_4$/ha significantly increased the nodules/plant and N concentration in nodules of pigeon pea over no application or (control). Gupta and Rathore (1995) observed that growth attributes (plant height and dry matter/plant) significantly increased with the application of full recommended dose of fertilizer to both the component crops in pigeon pea + sesame intercropping system over the lower doses of recommended dose. Namedo and Gupta (1999) found that application of 100% RDF (20 kg N and 50 kg P_2O_5/ha) and seed inoculation with *Rhizobium* and PSB gave the higher number of nodules/plant, dry weight of nodules/plant and shoot dry weight (g/plant) of pigeon pea over the 100% RDF alone and other treatments. In an experiment conducted at New Dehli, it was reported that application of fertilizer up to 75 per cent recommended dose (18 N + 46 P_2O_5 + 20 K_2O kg/ha) significantly enhanced the growth parameters *viz*., plant height, branches/plant and LAI of pigeon pea over control (Shivran *et al.*, 2000). Similarly, Saxena *et al.* (2001) recorded significant increase in growth parameters *viz*., plant height, leaf area index (LAI), dry matter accumulation, crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) of soybean with application of 20 kg N + 60 kg P_2O_5 + 40 K_2O kg/ha over control. Singh and Pal (2003) observed that application 100% RDF significantly increased the plant height, dry matter production and leaf area index of pigeon pea in comparison to 50% RDF and control. In a three year field experiment at Kanpur (UP) on pigeon pea, Verma *et al.* (2004) stated that application of zinc (foliar spray of 0.5% $ZnSO_4$) significantly increased the plant height, number of leaves and branches/plant of pigeon pea over seed soaking (0.5% $ZnSO_4$) and seed soaking (0.5% $ZnSO_4$ + foliar spray) treatments. Ramesh *et al.* (2006) conducted a field experiment on growth of pigeon pea as influenced by different treatments of organic manures (cattle dung @ 4 t/ha, vermicompost @ 3 t/ha and poultry manure @ 2 t/ha) and found that among organic sources, cattle dung recorded the maximum crop growth in terms of plant height, number of branches/plant and biomass accumulation, vermicompost remained intermediate while poultry manure recorded the lowest values of above parameters but was superior to control.

Patil and Padmani (2007a) while working on pigeon pea at Junagadh (Gujarat) observed that application of 100% RDF (25 N + 50 P_2O_5 + K_2O 0.0 kg/ha) significantly increased the plant height, branches/plant and number of nodules/plant over 50% RDF and control, however it was at par with 75% RDF. Singh (2007) conducted a field experiment at BHU, Varanasi and found that significantly increased plant height, number of branches and dry matter/plant of pigeon pea with the application of 50% RDF + 5 t FYM/ha which was remained at par with 10 t FYM and 100% RDF. Singh and Singh (2012) results revealed that the application of phosphorus 75 kg ha^{-1} gave the higher plant height, branches/plant, dry matter production/ plant, chlorophyll content (SPAD), leaf area and LAI which were significantly superior over 25 kg P_2O_5/ha and control but remained at par with 50 kg P_2O_5/ha during both the years. A field experiment was carried out by Saritha *et al.* (2012) reported that application of 150% RDF + vermicompost @ 1 t/ha produced higher plant height, no. of branches/plant leaf area, leaf area index (LAI), dry matter production/plant as compared to 200% RDF + vermicompost @ 2 t/ha). While working on pigeon pea, Kumawat *et al.* (2013b) carried out a field study on pigeon pea results revealed that application of 100% RDF + 50% RDN +5 kg Zn/ ha significantly increased the plant height (216.7 cm) and branches/plant (21.6) which was at par with 50% RDF + 100% RDN + 5 kg Zn/ha and superior to remaining nutrient management treatments. Singh *et al.* (2014) carried out field experiment at Shamli (UP) results revealed that plant height, no. of branches/plant and dry matter production/plant of pigeon pea were higher significantly recorded with the application of 90 P_2O_5/ha and 40 S/ha significantly superior over control 30 and 60 kg P_2O_5 and 20 kg S/ha, respectively. Sahay *et al.* (2015) carried out a field experiment at Varanasi on pigeon pea and reported that application of 100% RDF + 5 t FYM + *Rhizobium* + PSB gave higher plant height, numbers of branches and dry matter accumulation /plant followed by 50% RDF + 5 t FYM + *Rhizobium* + PSB.

Rathod *et al.* (2016) carried out an field experiment at Gulbarga found that application of RDF+$ZnSO_4$ @ 15 kg/ha increased the plant height, number of primary branches and secondary branches of pigeon pea however, it was on par with RDF+$ZnSO_4$ @ 25 kg/ha and significantly superior to rest of the treatments. Pal *et al.* (2016) observed that among the nutrient management practices, application of 100% recommended dose of fertilizer + 2.5 t vermicompost recorded significantly higher growth characters i.e. plant height, no. of branches, dry matter accumulation/ plant, LAI nodules/plant, dry weight of nodules/plant as compared to rest of the nutriment management practices. Singh *et al.* (2016a) conducted a field experiment at Ranchi (Jharkhand) reported that among the RDF (recommended dose of fertilizer) levels application of 200% RDF (30:60:30:30 kg NPKS/ha) gave significantly higher growth characters such as plant height, no. of primary and secondary branches/ plant, LAI, no. of nodules/plant and dry weight of nodules/plant, however it was at par with 150% RDF and superior to 100% RDF.

Effect of integrated nutrient application on yield attributes and yield

Ali (1981) concluded that application of 40 kg P_2O_5/ ha significantly increased the grain yield of pigeon pea (9.66 q/ha) over the 20 kg P_2O_5/ha. Chauhan and Singh (1981) found that application of 80 kg P_2O_5/ha obtained the maximum yield of pigeon pea (69.5%) higher than control. Thakur *et al.* (1988) found that application of 20 kg N + 50 kg P_2O_5/ha significantly increased the seed yield of pigeon pea (from 1.28 to 1.70 t/ha) but further increase the rate of N, P rate gave no additional seed yield. Kene *et al.* (1990) reported that application of 37.5 kg N + 75 kg P_2O_5 + 20 kg K_2O + 10 kg $ZnSO_4$/ha significantly improve the grain yield of pigeon pea (861 kg/ha) over control (283 kg/ ha). Billore *et al.* (1993) an experiment was conducted at Sehore (MP) and observed that maximum seed yield highest under application of 100 + 75% (20 N + 60 P_2O_5 kg/ha) fertility levels to pigeon pea + soybean intercropping over remaining fertility levels. Padmalatha and Rao (1993) reported that application of 30 kg N + 75 kg P_2O_5 + K_2O 0.0 kg/ha significantly increased the dry matter and seed yield of pigeon pea over 20 kg N + 20 kg P_2O_5 + K_2O 0.0 kg/ha. Singh *et al.* (1994) reported that maximum seed yield of pigeon pea (1.85 t/ha) with the application of 40 kg N + 80 kg P_2O_5 + 40 kg K_2O/ha which also gave highest benefit cost ratio (1.57). Arunachalam *et al.* (1996) observed that seed yield of pigeon pea was highest with application of 40 kg P_2O_5 + 20 kg K_2O/ha. Srinivas and Raju (1997) reported that yield and yield attributing charters *viz*., number of pods per plant, 100-grain weight and grain yield of pigeon pea significantly increased with application 60 kg P_2O_5/ha than the 0 and 30 kg P_2O_5/ ha. Under rainfed conditions at Morena (M.P.), Yadav *et al.* (1997) found that pods/plant and test weight significantly superior under pigeon pea + blackgram (100% RF *i.e.* 20 kg N and 50 kg P_2O_5/ha) as compared to sole pigeon pea, whereas, seed yield/plant was higher in pure pigeon pea. In a two year investigation at New Dehli on sandy loam soil, application of 100% recommended dose of fertilizer (18 N + 46 P_2O_5 + 20 K_2O kg/ha) significantly increased pods/plant, seeds/pod and 1000-seed weight of pigeon pea during 1997-1998 and 1998-1999 over control (Shivran and Ahlawat, 2000). Adhikary and Sarkar (2000) reported that pigeon pea + groundnut paired row system at 60 kg P_2O_5/ha gave the highest pigeon pea seed yield and monetary advantage.

Jat and Ahlawat (2003) reported that higher yield attributes (pods/plant and seeds/pod) and grain yield of pigeon pea and pigeon pea equivalent yield were recorded in pigeon pea+ groundnut intercropping system along with 40 kg P_2O_5/ha. In another experiment, conducted at Coimbatore (Tamil Nadu) Velayutham *et al.* (2003) opinion that growing of pigeon pea in paired row with full RDF (25 N + 50 P_2O_5 kg/ha) + greengram recorded more plant height, number of pods/plant, number of seeds/pod, 100-seed weight and seed yield which was at par with paired row pigeon pea full dose of RDF (20 N + 50 P_2O_5 kg/ ha) + greengram (2.5 N + 5.0 P_2O_5 kg/ha). Singh and Pal (2003) from New Dehli reported that application of 100% RDF significantly increased braches/plant, number of pods/branch, pod length, weight/pod, number of grains/pod, weight of grains/pod, 1000-grain weight, grain and stalk yield of pigeon pea over 50% RDF and control. Verma *et al.* (2004) from Kanpur (UP) reported that application of zinc (foliar spray of 0.5% $ZnSO_4$) significantly increased the number of pods/plant number of seeds/plant, weight of seeds/plant, test weight and seed yield of pigeon pea over other treatments.

Kumar and Kushwaha (2006) observed that pods/plant and seed and stalk yield of pigeon pea significantly improved with application of 80 kg P_2O_5/ ha over (20 and 40 P_2O_5/ha), but it was remained at par with 60 kg P_2O_5/ha. The plant height, seeds/pod and 100-seed weight did not affected significantly by application of different levels of phosphorus (20, 40 and 80 P_2O_5/ha). Ramesh *et al.* (2006) carried out a field experiment at Bhopal, reported that among different sources, chemical fertilizers recorded the higher number of pods/plant in pigeon pea which were at par with cattle dung application. Application of vermicompost, phosphocompost and poultry manure resulted in similar number of pods/plant which were at par with each other but significantly superior to control. Seeds/pod and 100-seed weight did not differ significantly among sources. Seed yield/plant was the highest in chemical fertilizer and the lowest in control. Karwasra and Kumar (2007) in a four year study (2002 -2005) on pigeon pea concluded that 40 kg N + 80 kg P_2O_5/ha significantly improved grain yield in all the four years over control and other lower levels *i.e.* NPK tried in different combinations. The average increase in grain yield due to 40 kg N + 80 kg P_2O_5/ha over control was 62.5, 54.0, 89.3 and 68.2 per cent during 2002, 2003, 2004 and 2005, respectively. An experiment conducted during *kharif* season on pigeon pea + greengram intercropping under rainfed condition, it was found that application of 40 kg P_2O_5 + 25 kg S + PSB significantly increased the seed and stalk yield of pigeon pea over control, however, it was at par with 40 kg P_2O_5 + 25 kg S/ha (Kumar and Rana, 2007). Patil and Padmani (2007b) reported that application of 100% RDF (25 N + 50 P_2O_5 + K_2O 0.0 kg/ha) significantly increased the yield and yield attributes *viz*., number of pods/plant, number of seeds/pod, test weight, grain yield/plant, grain and stover yield of pigeon pea over 50% RDF and control, but it was remained at par with 75% RDF.

Reddy *et al.* (2007) in a field experiment at Warangal (Andhra Pradesh) concluded that application 100% RDF (20 N + 50 P_2O_5 + 20 K_2O + 20 S kg/ha) + 30 kg sodium molybadate to pigeon pea significantly increased pods per plant and seed yield over 100% RDF and control and other treatments and being at par with each other, however, plant height and 100 seed weight were not influenced significantly by micronutrients along with RDF. Singh (2007) reported that maximum grain yield and stover yield of pigeon pea were observed with the application of 50% RDF + 5 t FYM/ ha over the other treatments. Ghosh *et al.* (2009) carried out field experiment of soybean/sorghum intercropping and found that integrated use of organic and inorganic-fertilizer recorded significantly higher soybean equivalent yield (SEY) over control and sole inorganic fertilizer. The highest SEY was recorded with 75% NPK+4 t FYM/ha.

Deshbhratar *et al.* (2010) at Nagpur reported that application of 50 kg P_2O_5/ha (through DAP) and 20 kg S/ha (though elemental sulphur) significantly increased the number of pods/plant, number of seeds/ pod, grain, straw yield/plant, and grain, straw yield over control and 25 kg P_2O_5/ha. Sharma *et al.* (2010a) revealed that application of RDF + 15 kg $ZnSO_4$/ha significantly higher number of pods/plant, number of seeds/pod, 100-seed weight and seed yield of pigeon pea followed by RDF + 25 kg $ZnSO_4$ and RDF + seed treatment with sodium molybdenum @ 4 g/kg as compared to control. Reddy *et al.* (2011) reported that application of 50% RDF + seed treatment with *Rhizobium* @ 200 g/kg seeds recorded significantly higher number of branches/plant, pods and higher grain yield of pigeon pea (16.3, 151.3 and 1358 kg/ha, respectively) as compared to seed treatment with *Rhizobium* @ 200 g/kg seeds + 100 % RDF + FYM @ 5 t/ ha (14, 142 and 1325 kg/ha, respectively).

Goud *et al.* (2012) reported that sowing at 90 x 30 cm with application of 30:60:30:20:15 kg N: P_2O_5: K_2O: S: $ZnSO_4$/ha obtained higher number of pods/plant (180 cm, 4.6 and 163, respectively) as compared to sowing at 75 x 25 cm with application of 20:45:20:20:15 kg N: P_2O_5: K_2O: S: $ZnSO_4$/ha recorded lower values (175 cm, 4.5 and 138, respectively) in pigeon pea. Meena *et al.* (2012) found that application of fertilizer (60:60:40 NPK kg/ha) at soil-test based recommended rates produced 1.44 t/ha of grain yield of pigeon pea which was significantly higher as compared to unfertilized control (0.94 t/ha). Singh and Singh (2012) carried out a field study on pigeon pea reported that application of phosphorus 75 kg/ha produced highest grain, stalk, biological yield and harvest index which was significantly superior to 25 kg P_2O_5/ha and control but remained at par with 50 kg P_2O_5/ha. Saritha *et al.* (2012) found that highest seed yield of pigeon pea was recorded in 150% RDF + vermicompost @ 1 t/ha which was comparable with 200% RDF + vermicompost @ 2 t/ha). Gangaiah *et al.* (2013) conducted two years field study on pigeon pea during *kharif*, results revealed that higher plant height, pods/plant 1000-seed weight, seeds/pod, seed yield, biological yield and harvest index were recorded with the application of RDF (recommended dose fertilizers N 20 and P 26.4 kg/ha) over the rest of the treatments. Umesh and Shankar (2013) carried out a field experiment at Bangalore on pigeon pea, results revealed significant increase in pods/plant, test weight, grain (1759 kg/ha) and stalk yield (6004 kg/ha) with application of N:P:K:S:$ZnSO_4$ @ 50:100:75:10:12.5 kg/ha as compared to other treatments. Pandey *et al.* (2013) reported that application of FYM @ 5.0 t/ha or vermicompost @ 2.5 t/ha with 100 % RDF proved equally effective for enhancing the grain yield of pigeon pea and both produced significantly higher grain yield than RDF alone. From Varanasi Kumawat *et al.* (2013b) observed that higher pods/plant and 1000-seed weight was recorded in the treatment of 100% RDF + 50% RDN +5 kg Zn/ha which was statistically similar with 50% RDF + 100% RDN + 5 kg Zn/ha and significantly superior to rest of the treatments. Kumawat *et al.* (2013a) reported that significantly higher yield attributes viz., weight of pods/plant (122.22 and 115.78 g), no. of seeds/pod (3.34 and 3.3) seed yield/plant (125.6 and 120.0 g) seed yield (2.4 and 1.7 t/ha) and pigeon pea equivalent yield (2.7 and 1.9 q/ha) and land equivalent ratio (1.6 and 1.5) were found the application of 100% RDF + 50% RDN +5 kg Zn ha/ha and this treatment was found at par with 50% RDF + 100% RDN + 5 kg Zn/ ha during 2008-09 and 2009-2010.

From Shamli (UP) Singh *et al.* (2014) reported that higher yield attributes *viz*., pods/plant, pod weight/ plant, grains weight/plant, 1000-grain weight and yields *viz*., seed, stover and biological yield and harvest index were recorded with the application of 90 P_2O_5/ha but it was statistically comparable with 60 kg

P_2O_5/ha and significantly superior to control and 30 kg P_2O_5/ha. Zadode *et al.* (2014) field experiment was conducted on PKV-TARA pigeon pea at Akola, results reveals that fertilizer level of 25:50:20:20 kg NPKS/ha significantly increased the grain yield (25.70 q/ha) and harvest index (32.23%) than fertilizer level of 12.5:25:10:10 kg NPKS/ha. Similarly in regard to stover yield did not shown significant difference. Aher *et al.* (2015) conducted a field study on pigeon pea and reported that yield attributes *viz*., number of pods/ plant, weight of pods and weight of seeds/plant and yields (seed, stover and biological yield) were increased due to application of 100 kg P_2O_5/ha but it was at par with 50 and 75 kg P_2O_5/ha and significantly higher than 25 kg P_2O_5/ha. From Varanasi (UP) Sahay *et al.* (2015) reported that no. of pods/plant test weight, grain yield stalk yield and harvest index of pigeon pea significantly increased with the application of 100% RDF + 5 t FYM + *Rhizobium* + PSB and it was at par with 50% RDF + 5 t FYM + *Rhizobium* + PSB.

While working on pigeon pea Rathod *et al.* (2016) reported that application of $ZnSO_4$ @ 15 kg/ha along with RDF gave higher no. of pods/plant, pod weight/ plant seed weight/plant 100-seed weight and grain yield of pigeon pea however, it was statistically similar with RDF+$ZnSO_4$ 25 kg/ha. Pal *et al.* (2016) working on pigeon pea found that yield attributes such as no. of pods/plant, no. of grain/pod weight of pods/plant, grain weight/plant and test weight and grain yield (1831.8 kg/ha) and stalk yield (8221.6 kg/ha) over the remaining treatments. Singh *et al.* (2016a) observed that among the RDF (recommended dose of fertilizer) levels application of 200% RDF (30:60:30:30 kg NPKS/ha) gave higher yield attributes like that no. of pods/plant, no. of seeds/pod, 100-seed weight, grain yield and stover yield of pigeon pea but it was statistically similar to 150% RDF and significantly superior to 100% RDF.

Effect of integrated nutrient application on nutrient content and uptake

Singh *et al.* (1988) observed that application of 10 and 20 kg $ZnSO_4$/ha significantly increased the Zn content and uptake by seed of pigeon pea. Kene *et al.* (1990) conducted an experiment at Nagpur and recorded that application of 37.5 kg N + 75 kg P_2O_5 + 20 kg K_2O + 10 kg $ZnSO_4$/ha significantly improve the N, P and K content in grain and stalk of pigeon pea over control. Srivastava and Srivastava (1993) reported that sulphur had a significant effect on uptake of sulphur by pigeon pea. Rao and Reddy (1997) reported that uptake of P increased upto 60 kg/ha and protein content also increased with increasing P rates. Kantwa *et al.* (2005) reported that the phosphorus uptake by pigeon pea sole and pigeon pea + urdbean intercropping system was significantly more in 40 kg P_2O_5/ha over unfertilized crop. Ramesh *et al.* (2006) conducted a field experiment at Bhopal applying different organic manures (cattle dung 4 t/ha, vermicompost 3 t/ha and poultry manure 2 t/ha) to pigeon pea and reported that the highest protein content in seed was recorded with the application of cattle dung (21.25%) followed by vermicompost (20.90%) and poultry manure (20.87%). Singh (2007) observed that application of 50% RDF + 5 t FYM/ha to pigeon pea significantly recorded higher uptake of N (150 kg/ha), P (31.9 kg/ha) and K (98.7 kg/ha) and remained at par with 10 t FYM/ha and 100% RDF treatment. While working on pigeon pea at Junagadh (Gujarat), Patil and Padmani (2007c) observed that 100% RDF (25 N : 50 P_2O_5 : K_2O 0 kg/ha) caused significant increase N, P, and K content in grain and stalk of pigeon pea, highest protein content and protein yield over the 50% RDF and control, whereas, it was at par with 75% RDF. From New Dehli, Kumar and Rana (2007) reported that application of 40 kg P_2O_5 + 25 kg S + PSB significantly improved the P and S uptake by pigeon pea over control and 40 P_2O_5 /ha, however, it was remained at par with 40 kg P_2O_5 + 25 kg S/ha. Kumawat *et al.* (2012) carried out a field study for two years on pigeon pea reported that application of 100% RDF+50% RDN+5 kg Zn/ha significantly increased CEC of roots (68.73 and 66.14 meq 100 g/dry roots), root N content (3.03 and 2.80%) protein content (21.31 and 21.11%) and protein harvest (kg/ha) (534.49 and 364.01 kg/ha) which was at par with 50% RDF + 100% RDN + 5 kg Zn/ha and significantly superior to rest of the integrated nutrient treatments during both the years of study. Gangaiah *et al.* (2013) reported that significantly N and P content in grain and their uptake improved with the application of RDF (N 20 and P 26.4 kg/ha), whereas the Fe and Zn content in grain was higher noted with the application of RDF through FYM. Umesh and Shankar (2013) observed that application of N:P:K:S:$ZnSO_4$ @ 50:100:75:10:12.5 kg/ha significantly improved the NPK uptake by pigeon pea over rest of the nutrient levels. Working on pigeon pea Zadode *et al.* (2014) observed that application of 25:50:20:20 kg NPKS/ha significantly improved the N, P, K and S uptake by crop which was superior over 12.5:25:10:10 kg NPKS/ha.

Aher *et al.* (2015) reported that quality protein content (20.52 %) was improved significantly by the application of higher levels of phosphorus @ 100 kg P_2O_5 /ha which was at par with 50 and 75 kg P_2O_5/ha than 25 kg P_2O_5/ha. Sahay *et al.* (2015) observed that N, P, K content in grain and stalk were improve significantly with the fertilized plot of 100% RDF + 5 t FYM + *Rhizobium* + PSB and this treatment was on par with 50% RDF + 5 t FYM + *Rhizobium* + PSB in respect to above parameters. Similarly, application of 100% RDF + 5 t FYM + *Rhizobium* + PSB also improved significantly the protein content in grain and stalk of pigeon pea. However this treatment was statistically at par with 50% RDF + 5 t FYM +

Rhizobium + PSB. Singh *et al.* (2016b) while working on pigeon pea reported that improved N, P, K and S uptake by grain as well as stover increased with the increasing level of RDF 200% but it was at par with 150% and significantly higher over 100% RDF.

Effect of integrated nutrient application on economics

Kumar and Ahlawat (1986) found that application of 50 kg N/ha to pigeon pea significantly increased the pigeon pea equivalent yield and net return over the 0 and 25 kg N/ha. Billore *et al.* (1991) conducted a field trail on pigeon pea intercropped with soybean and reported that in case of sulphur application, the improvement in net return was upto 40 kg S/ha. Gupta and Rathore (1995) found that the maximum pigeon pea equivalent yield, gross returns and net returns were recorded with application full dose of RDF to both components over remaining RDF doses. Yadav *et al.* (1997) reported that pigeon pea equivalent yield and benefit : cost ratio higher were recorded in the pigeon pea + sesame (100% RF) than the soybean and clusterbean intercropping systems. Namedo and Gupta (1999) observed that maximum net return was obtained with 100% RDF (20 N and 50 P_2O_5 kg/ha) + *Rhizobium* + PSB followed by 100% RDF + *Rhizobium* and 100% RDF + PSB. Shivran *et al.* (2000) reported the maximum net return of Rs 22,675 from the cropping systems when pigeon pea was fertilized with 60 kg P_2O_5/ha. Kumar and Rana (2007) found that application of 40 kg P_2O_5 + 25 kg S/ha + PSB significantly higher net return and B:C ratio over 40 P_2O_5/ha and control, which was at par with 40 kg P_2O_5 + 25 kg S/ha. Patil and Padmani (2007b) reported that application of 100% RDF (25 N + 50 P_2O_5 + K_2O 0.0 kg/ha) gave the highest net returns, however, the highest net ICBR was obtained with 75% RDF over 50% RDF and control. Singh (2007) reported that net returns of pigeon pea were observed with the application of 50% RDF + 5 t FYM/ha over other treatments. In a study Pandey and Kushwaha (2009) reported that combined seed inoculation with *Rhizobium* + PSB plus 100% RDF recorded significantly higher net returns (Rs. 38,233/ha) followed by *Rhizobium* + PSB inoculation with 50 % RDF (Rs. 32,437/ha) of pigeon pea.

Sharma *et al.* (2010b) from Karnataka reported that application of 100% RDF + 15 kg $ZnSO_4$/ha significantly gave maximum gross return, net return and B:C ratio over control. Sharma *et al.* (2010a) reported that pigeon pea + green gram intercropping system with RDF + 2 % urea spray at 15 and 30 days after harvest of intercrops recorded significantly higher pigeon pea equivalent yield (19.53 and 18.99 q/ha), gross returns (Rs. 31,439 and 30,576/ha), net returns (Rs. 23,984 and 22,928/ha) and B: C ratio (3.81 and 3.63, respectively) over other intercropping systems. Tiwari *et al.* (2011) observed that pigeon pea + urdbean cropping with the application of PSB + FYM @ 2.5 t/ha recorded higher net returns (Rs. 27,911/ha) and B:C ratio (1.58) compared to pigeon pea + maize cropping system (Rs. 14,293/ha) with the B:C ratio of 0.70. Meena *et al.* (2012) revealed that adoption of induced defoliation in pigeon pea along with NPK + FYM gave the highest system productivity whereas significantly higher net returns (Rs. 32,400/ha) was found under NPK + induced defoliation over the other treatments. Vishwanatha *et al.* (2012) observed that maximum gross returns (Rs. 80,302 and Rs. 77,448/ha), net returns (Rs. 62,308 and 59,718/ha) and B:C ratio (3.46 and 3.37) were noted with the application of 100% RDF to pigeon pea + 100% RDPK and 50% RDN to sunflower as basal + 50% RDN as top dress at 45 DAS to sunflower based on population followed by 100% RDF to pigeon pea and 100% RDF to sunflower as basal dose based on population, respectively. Sharma *et al.* (2012) reported that 100 % RDF, FYM @ 5 t/ha and *Rhizobium* + PSB + PGPR gave significantly higher net returns, of Rs. 27,608, 29,764, and 27,330/ha, respectively. Similar, results were obtained in case of B:C ratio (1.49, 1.59 and 1.52, respectively). Gangaiah *et al.* (2013) observed that maximum gross return, net return and B:C ratio were recorded in RDF (N 20 and P 26.4 kg/ha) over the rest of the treatments. Umesh and Shankar (2013) reported that application of N:P:K:S:$ZnSO_4$ @ 50:100:75:10:12.5 kg/ha fetched maximum net return and B:C ratio as compared to rest of the nutrient levels. Kumawat *et al.* (2015) working on pigeon pea revealed that maximum gross return (130.74×10^3 Rs/ha), net return (109.28×10^3 Rs/ha), B:C ratio (5.11), production efficiency (8.90 kg/ha/day) and economic efficiency (401.07 Rs./ha/day) were observed under 100% RDF + 50% RDN +5 kg Zn/ha and it was found similar with 50% RDF + 100% RDN + 5 kg Zn/ha. Rathod *et al.* (2016) reported that application of 15 kg $ZnSO_4$/ha along with RDF gave maximum gross return, net return and B:C ratio which was statistically at par with RDF + $ZnSO_4$ 25 kg/ha. Singh *et al.* (2016a) working on pigeon pea found that maximum gross return and net return was recorded in 200% RDF and it was at par with 150% RDF and significantly superior to 100% RDF.

Effect of integrated nutrient application on soil fertility

Srinivasan and Ahlawat (1984) found that available P in sandy loam soil significantly improved by application of 90 kg P_2O_5/ha over the lower levels of phosphorus (0, 30 and 60 kg/ha), while N and K remained unaffected. Singh and Faroda (1986) observed that total N, available N and P status of soil increased with the application of 40 and 80 kg P_2O_5/ha in pigeon pea. Application of FYM alone or in combination with chemical fertilizers significantly increased the residual status of available nitrogen and phosphorus in soil (Dudhat *et al.* 1997). Ramesh *et al.* (2006) found significantly higher organic carbon (0.63%) due to application of 4 t/ha cattle dung manure (0.63%) as compared to either chemical fertilizer (0.54%) or unfertilized control (0.50%). Higher values of available N (178.7 kg/ha) and K (578.7 kg/ha) in soil were also observed in the plots manured with cattle dung than the control. Deshbhratar *et al.* (2010) reported that application of 20 kg S/ha (through elemental sulphur) significantly improved the available N, P and K over control. Whereas, maximum sulphur content (9.52 mg/kg) was recorded with the application of 50 kg S/ha. On other hand the application of 75 kg P_2O_5/ha (through DAP) significantly improved available soil N, P and S over control. However, the maximum potassium was found in control. Dubey and Vyas (2010) reported that application of 50 % RDF + FYM @ 5 t/ha + bio-fertilizers proved conducive to sustain the soil health by enhancing the organic carbon, available nutrient status by both crop (pigeon pea and soybean) by reducing the bulk density of soil. Reddy *et al.* (2011) reported that application of 50% RDF through inorganic fertilizer + seed treatment with *Rhizobium* culture and PSB improves nutrient status of soil.

Saritha *et al.* (2012) observed that among the nutrient levels, significantly higher available N (201.90 kg/ha) and P_2O_5 (29.78 kg/ha) was recorded in the fertilized plot 150% RDF + vermicompost @ 1 t/ha as compared to 200% RDF + vermicompost @ 2 t/ha) but K_2O did not show any significant differences. Meena *et al.* (2012) reported that the soil-test based NPK resulted in conjunctive use of fertilizer NPK and FYM improved soil health as revealed by lower bulk density and higher water holding capacity over sole fertilizer treatment. Singh and Singh (2012) reported that application of 75 kg P_2O_5/ha gave higher total nitrogen, phosphorus, potassium and sulphur uptake and was significantly superior over 25 kg P_2O_5/ha and control. Gangaiah *et al.* (2013) found that application of RDF through FYM gave higher values of organic carbon, available N and P in soil, whereas the higher values of available K was in RDF thorough vermicompost and lowest in control. Pandey *et al.* (2013) reported that pigeon pea + urdbean intercropping system with application of FYM @ 5.0 t/ha or vermicompost @ 2.5 t/ha and RDF improved bulk density, organic carbon and increased available N, P and K content of the soil over initial soil value. Zadode *et al.* (2014) reported that significantly higher available N, P, K and S in soil were noted with the application of 25:50:20:20 kg NPKS/ha as compared to 12.5:25:10:10 kg NPKS/ha. Nagar *et al.* (2016) carried out field study on pigepnpea reported that among combined use of organic manure, application of FYM + phosphocompost and pigeon pea stalk + phosphocompost resulted in improvement of physical, chemical and biological properties of soil over recommended dose of fertilizer (RDF) application. Kumawat *et al.* (2015) reported that after harvest of crop of pigeon pea significantly improve the organic carbon, available N, P, K, S and Zn due to application of 100% RDF + 50% RDN +5 kg Zn/ha. From Ranchi Singh *et al.* (2016b) reported that application of 200% RDF improved the organic carbon, available N, P, K and S in soil after harvest of crop but it was at par with 150% and significantly higher over 100% RDF.

Conclusion

Good agronomic practices (GAP) and their different components shown potential to excel under change climate condition, there is need to adopt the all the component of advocated technology as a unit not to choose few of them at will, which were leading to several complication soil health hazards and poor response of technology. The using of high yielding varieties with optimum application of nutrient either organic or inorganic sources to pigeon pea increases the production, productivity, profitability and also improved the soil health which is manner of sustainable agro-ecosystem.

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