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Effect of sunflower stover and nutrients management on soil biological properties and available nitrogen and phosphorus at different stage of pigeonpea growth under pigeonpea-sunflower cropping system

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A fixed plot field experiment was carried out during 2008-09 and 2009-10 at New Delhi, India to study the "effects of sunflower stover, nitrogen and phosphorus management on soil health under pigeonpea-sunflower cropping system''. *Kharif* season experiment in the first year was laid out in split-plot design, assigning sunflower stover incorporation (8 t/ha) and no stover incorporation (control) to main plots and combination of P levels and bio-fertilizers {control, 15 kg P/ha, 15 kg P/ha + phosphate solubilizing bacteria (PSB), and 30 kg P/ha} to sub-plots. The spring season experiment of both years was laid out in split-split plot design in which NP doses to sunflower crop {control, 50% recommended dose (RD) of NP, and recommended dose (RD) of NP (80 kg N + 15 kg P/ha} were applied in sub-sub plots. *Kharif* season experiment in the second year was laid out in split-split plot design to investigate the residual effect of NP doses applied to spring season crop in sub-sub plots. Treatments were replicated thrice during both years. Results reveal that the sunflower stover incorporation resulted in better soil biological properties in terms of dehydrogenase activity, alkaline phosphatase activity and microbial biomass carbon (MBC). Available soil NH_4-N and NO_3-N, available P initially reduced due to sunflower stover incorporation but at latter stages, these nutrients in soil increased. Among the various P levels, application of 30 kg P/ha recorded maximum values of soil dehydrogenase, MBC and available P, NH_4-N and lowest values of alkaline phosphatase and NO_3-N. With respect to the residual effect of nitrogen and phosphorus applied to sunflower, among the various levels of N and P, recommended dose (RD) of N and P resulted in better soil biological properties under study and higher values of available N and P.

Key words: Available nutrients, biological properties, cropping system, nutrients management, sunflower stover management.

INTRODUCTION

Nutrient's mining has occurred in many soils due to lack of affordable fertilizer sources and where meager or no organic residue is returned to the soils. The degradation of soil fertility owing to over mining of nutrients and inadequate replenishment through fertilizers can only be curbed through adoption of integrated nutrient management

(INM) technology. The low-input sustainable agriculture (Grubinger, 1992) and reduced chemical input (Kirchner et al., 1993) concepts focus on the re-consideration of agricultural practices, such as burying crop residues and green manuring, in order to maintain the soil organic matter at adequate levels and preserve the whole soil organic status. Therefore, there is urgent need to use all available resources of nutrient to maintain the productivity and fertility at a required level. Among the available organic sources of plant nutrients, crop residue is one of the most important sources for supplying nutrients to the crops.

Sunflower has potential to yield 4-6 t/ha crop residue. This great amount of crop residues are neither used as feed for livestock nor suitable for fuel due to low energy value per unit mass. However, its residue contain major plant nutrients in the range of 0.45 to 0.60% N, 0.15 to 0.22% P and 1.80 to 1.94% K along with secondary and micronutrients (Babu et al., 2014), so its recycling in the soil may be one of the best alternative practices for replenishing the depleted soil fertility. Decomposition of plant residues is the microbially mediated progressive breakdown of organic material into C (biomass or CO_2) and other nutrients (Kumar and Goh, 2000). Crop residues decompose into two distinct phases, an initial rapid phase, in which about 70% of C initially present in the residues is lost as CO_2, followed by a slower phase during which the more resistant fraction is decomposed (Wang et al., 2004). Residue factors include chemical composition, C/N ratio, lignin content and the size of residue particles (Johnson et al., 2007). C/N ratio of residue is a common indicator of residue quality but is not necessarily an accurate predictor of decomposition rate (Handayanto et al., 1994). The incorporation of crop residues into the soil modifies its chemical and biochemical properties, including soil-enzyme activity (Dick et al., 1983), the behaviour of which has often been related to the amount (Speir and Ross, 1983) as well as to the type of organic matter (Perucci et al., 1984). Soil enzymes play a major role in nutrient availability (Martens et al., 1992). In soils, enzymes may be associated with viable cells, dead cells (abiontic enzymes), cell debris and immobilized enzymes in the soil matrix (Burns, 1982).

Dehydrogenase is considered to play an important role in the initial stages of the oxidation of soil organic matter (Ross, 1971) by transferring hydrogen and electrons from substrates to acceptors. Unlike dehydrogenase activity, which can occur only in viable cells, phosphatases have catalytic capabilities both as endoenzymes and as accumulated exo-enzymes in the soil matrix (Kiss et al., 1975). It is very well known that the activity of soil enzymes is higher in the rhizosphere (Tarafdar and Rao, 1990). Pulses have the tap root system and larger rhizospheric area and more enzymatic activity. Among the pulses, pigeonpea is the one of the most important crop, which plays a pivotal role in maintaining the soil fertility. Due to longer root system of pigeonpea, it is often considered as a natural and/or biological plough. Pigeonpea added up to 60 kg of N/ha to the soil and accumulated up to 6 kg of P/ha (Myaka et al., 2006). Phosphorus is one of the most important primary elements from crop production point of view. It exists in nature in a variety of organic and inorganic forms, but primarily in either insoluble or very poorly soluble inorganic forms (Paul and Clark, 1989). Soluble forms of P fertilizers applied to the soil are easily precipitated as insoluble forms. This often leads to an excess application of P fertilizer to crop land. This unmanaged excess may be both an environmental and economic problem. Phosphate solubilizing bacteria solubilise insoluble P by producing various organic acids including oxalic, citric, butyric, malonic, lactic, succinic, malic, gluconic, acetic, glyconic, fumaric, adipic and 2-ketogluconic acid (Moghimi and Tate, 1978). Many researchers proved that PSB plays a key role in soil organic P (P_o) transformations (Frossard et al., 1995) through excretion of phosphatase enzymes (Eichler et al., 2004), mineralization of P from organic sources (Gressel and McColl, 1997), and also synthesis and release of P_o (Oberson et al., 2001). This available P is taken up by plants (Banik and Dey, 1981).

In view of the limited information available on the judicious utilization of locally available crop residue and externally inputs especially fertilizers for long term basis and their effect on soil health, the present investigation “focuses on the effects of sunflower stover and nutrients management on soil biological properties and available nitrogen and phosphorus at different stages of pigeonpea growth under pigeonpea-sunflower cropping system in tropical condition of Delhi, India’’.

MATERIALS AND METHODS

Details of experimental field

A fixed plot field experiment was carried out during *kharif* (21.06.2008 and 24.06.2009) and spring seasons (17.02.2009 and 13.02.2010) of 2008-2009 and 2009-2010 for making a comparative assessment of sunflower stover management, P levels and N doses on the soil health under pigeonpea-sunflower cropping system at research farm of Division of Agronomy, Indian Agricultural Research Institute, New Delhi, situated at a latitude of 28°40’ N, longitude of 77°12’ E and altitude of 228.6 m above the mean sea level (Arabian Sea). The soils of experimental field was sandy clay loam belonging to order Inceptisol and having 145.0 kg/ha alkaline permanganate oxidizable N, 17.5 kg/ha available P, 226.0 kg/ha 1 N ammonium acetate exchangeable K and 0.40% organic carbon. The pH of soil was 7.5 (1:2.5 soil and water ratio). Field capacity,

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permanent wilting point and bulk density recorded were 17.0% (w/w), 6.30% (w/w) and 1.46 Mg/m^3, respectively in 0-15 cm soil depth.

Experimental design and treatments

Kharif season experiment in the first year was laid out in split-plot design, assigning sunflower stover incorporation (8 tonnes/ha) on 50% moisture basis for both years and no stover incorporation (control) to main plots and combination of P levels and bio-fertilizers {control**,** 15 kg P/ha, 15 kg P/ha+ phosphate solubilizing bacteria (PSB), 30 kg P/ha} to sub-plots. Spring season experiments of both years was laid out in split-split plot design in which NP doses to sunflower crop (control, 50% RD of NP, RD of NP (80 kg N+15 kg P/ha) were applied in sub-sub plots. *Kharif* season experiment in the second year was laid out in split-split plot design to investigate the residual effect of NP doses applied to sunflower crop in sub-sub plots. The treatments were replicated thrice during both years. The plot size was 17.4 x 15.0 m for main plot, 2.4 x 15.0 m for sub-plot and 2.40 x 4.0 m for sub-sub plots. Firm seed bed of fine tilth was prepared before sowing the crop. After the harvesting of pigeonpea crop (08.12.2008 and 14.12.2009), sunflower was sown on ridges at row distance of 60 cm. The plan of layout for spring crop was made exactly same as previous crop, only sub-plots were divided into sub-sub plots in sunflower to separate the residual and direct effect of treatments. Starter dose of N (25 kg/ha) was given to pigeonpea and phosphorous through diammonium phosphate was supplied as per treatment. Phosphorus was placed 3-5 cm below the seed with the help of metallic tube attached plough. Sunflower stover of the spring crop of sunflower was chopped with the help of chopper and incorporated in the soil as per treatments (8 t/ha) before the sowing of pigeonpea. Pigeonpea seed were inoculated with Microphos as per treatments. In sunflower crop, 50% RD of NP and RD of NP (80 kg N + 15 kg P/ha) respectively was supplied through urea and diammonium phosphate as per treatments. Pigeonpea ‘Pusa 992’ seed (15 kg/ha) was sown by ‘pora’ method in rows 60 cm apart. Plant to plant spacing was maintained 15-20 cm apart by adopting gap filling and thinning at appropriate time. For weed control, pre-emergence spray of stomp (pendimethalin) @ 1.0 kg/ha was done in pigeonpea. Beside, herbicide application one hand weeding was done at 30 days after sowing (DAS). Pigeonpea crop was infested with blister beetle and pod borer. In order to control these insects, two spraying of monocrotophos @ 0.04% were given. Pigeonpea was grown as per recommended practices and were harvested in the first fortnight of November in both year of experimentation.

Studies on soil biological properties

Biological properties of soil such as dehydrogenase activity estimated by the method described by Casida et al. (1964), alkaline phosphatase activity estimated by the method described by Tabatabai and Bremner (1969) and microbial biomass carbon estimated by the method described by Vance et al. (1987) and Numan et al. (1998) was used. These properties were analyzed at 30, 60, 120 DAS and at harvest of pigeonpea. Soil samples were taken from crop root (0-15 cm soil depth) by core sampler. The soil samples were air dried and kept in freezer until the analysis of the parameters.

Studies on soil available N and P

The composite soil samples were collected from 0-15 cm soil profile before sowing and 30, 60, 120 DAS and at harvest of pigeonpea. The soil samples were air-dried, ground and passed through 100 mm mesh sieve and were analyzed for NH_4–N and NO_3–N, P and K. The NH_4–N and NO_3–N were estimated by Magnesium Oxide-Devardas alloy method for soil extract (Keeney and Nelson, 1982) and expressed in kg/ha. The available P content in soil was estimated by Olsen et al. (1954) method and expressed in kg/ha.

Statistical analysis

All the data obtained from the experiment during two consecutive years were statistically analyzed using the *F*-test procedure given by Gomez and Gomez (1984). Critical difference (CD) values at P=0.05 were used for determining the significance of differences between means.

RESULTS

Effect of sunflower stover incorporation and nutrient management on selected soil biological properties

Dehydrogenase activity

In general, dehydrogenase activity (µ/g soil/day) increased in both years as the crop advanced in age, dehydrogenase activity comparatively higher during 2009 as compared to 2008 and the highest dehydrogenase activities were recorded at harvesting and the lowest at 30 DAS during both seasons (Table 1). Perusal of data indicates that sunflower stover incorporation recorded significantly higher values of dehydrogenase activities at all the growth stages of pigeonpea *viz.,* 30, 60, 120 DAS and at harvest during both years of experimentation over the control except at 30 DAS in 2008. Significantly higher values of dehydrogenase activities were recorded from all the levels of P over the control at all the growth stages of pigeonpea *viz.,* 30, 60, 120 DAS and at harvest during both seasons. Among the P levels, application of 30 kg P/kg recorded significantly higher values of dehydrogenase activities over the rest of the treatments at 30, 60 DAS and at harvest, being at par with 15 kg P/ha+PSB at 60 and 120 DAS during both the seasons and at harvest during 2008. Except 120 DAS stage, maximum value of dehydrogenase activity was observed with 30 kg P/ha. At 120 DAS, maximum value of dehydrogenase activities was found with 15 kg P/ha+PSB, followed by 30 kg P/ha during both the years of field experimentation. NP doses applied to preceding sunflower had significant residual effect on soil dehydrogenase activities of succeeding pigeonpea under pigeonpea-sunflower cropping system. Residual effect of RD of NP registered the highest soil dehydrogenase activities in succeeding pigeonpea at all the growth stages, however it remained statistically on par with the residual effect of 50% RD of NP at all the growth stages except at 30 DAS.

Alkaline phosphatase activity

Alkaline phosphatase activity (µg p-nitrophenol/g/h) was

Table 1. Direct effect of sunflower stover and P management and residual effect of NP on dehydrogenase activity in soil of pigeonpea.

Treatment	Dehydrogenase activity (µg TPF/g soil/day)							
	30 DAS		60 DAS		120 DAS		At harvest	
	2008	2009	2008	2009	2008	2009	2008	2009
Direct effect of SFS management								
Control	0.033	0.033	2.63	3.99	4.63	5.32	6.45	7.77
SFSI @8 t/ha	0.037	0.042	5.01	5.38	6.98	7.92	8.21	9.17
SEm±	0.001	0.001	0.04	0.04	0.10	0.04	0.15	0.08
CD (*P*=0.05)	NS	0.004	0.25	0.22	0.62	0.26	0.91	0.49
Direct effect of P levels								
Control	0.022	0.036	2.55	3.35	3.90	4.66	5.90	6.76
15 kg P/ha	0.029	0.033	3.92	4.80	5.55	6.11	7.35	8.21
15 kg P/ha+PSB	0.037	0.036	4.25	5.17	7.25	7.98	8.00	9.08
30 kg P/ha	0.051	0.045	4.55	5.42	6.50	7.73	8.07	9.83
SEm±	0.002	0.002	0.21	0.11	0.38	0.09	0.41	0.10
CD (*P*=0.05)	0.006	0.006	0.66	0.34	1.18	0.29	1.25	0.31
Residual effect of NP doses applied to sunflower								
Control	-	0.032	-	4.31	-	6.25	-	8.10
50% RD of NP	-	0.035	-	4.75	-	6.69	-	8.54
RD of NP	-	0.045	-	4.99	-	6.92	-	8.77
SEm±	-	0.002	-	0.10	-	0.13	-	0.09
CD (*P*=0.05)	-	0.005	-	0.28	-	0.37	-	0.27

SFSI: Sunflower stover incorporation, RD of NP: 80 kg N+15kg P/ha; SFS: sunflower stover; DAS: days after sowing CD: critical differences.

higher during the second year of experiment as compared to first year irrespective of treatments (Table 2). Alkaline phosphatase activity increased with the advancement in crop stages up to 120 DAS and there after the activity declined until maturity. Significantly higher values of alkaline phosphatase activity were recorded with sunflower stover incorporation over control during both seasons at all the growth stages *viz*., 30, 60, 120 DAS and at harvest. All the P levels significantly affected the alkaline phosphatase activity in soil at all the stages during both seasons. Significantly lower values of alkaline phosphatase activity were recorded with 30 kg P/ha at all the growth stages of pigeonpea during both the seasons. In contrast, application of 15 kg P/ha+PSB recorded significantly higher values of alkaline phosphatase activity at all the growth stages over the rest of the P levels during both the years. NP doses applied to preceding sunflower significantly reduced the alkaline phosphatase activity of succeeding pigeonpea under pigeonpea-sunflower cropping system. Residual effect of RD of NP (80 kg N+15 kg P/ha) recorded the lowest values of alkaline phosphatase activity at all the stages but it remains statistically on par with the residual effect of 50% RD of NP at all the growth stages. However, maximum values of alkaline phosphatase activity were observed with control.

Microbial biomass carbon (MBC)

Across the seasons, MBC values (mg/kg of soil) were marginally higher during 2009 than 2008 (Table 3). MBC registered marked increase with the advancement in crop growth stages up to harvest. Over the stages, maximum increase was observed at 120 DAS followed by at harvest. Significantly higher value of soil MBC recorded with sunflower stover incorporation over control during both the seasons at all the growth stages *viz.,* 30, 60, 120 DAS and at harvest, except at 30 DAS during 2008. All the P levels significantly increased the MBC content in soil over the control at all the stages during both seasons, except at 30 DAS during 2008 and at 60, 120 DAS and at harvest during 2009 at these stages, control being statistically at par with 15 kg P/ha. In 2008, maximum values of MBC were recorded with 15 kg P/ha+PSB at 30 and 60 DAS. However, in 2009 maximum values of MBC were recorded with 30 kg P/ha at all the stages *viz.,* 30, 60, and at harvest, except at 120 DAS. But both the

Table 2. Direct effect of sunflower stover and P management and residual effect of NP on alkaline phosphatase activity in soil of pigeonpea.

Treatment	Alkaline phosphatase activity (μg p-nitrophenol/g soil/h)							
	30 DAS		60 DAS		120 DAS		At harvest	
	2008	2009	2008	2009	2008	2009	2008	2009
Direct effect of SFS management								
Control	45.6	48.8	56.0	63.9	102.8	104.8	63.8	64.8
SFSI @8 t/ha	54.8	62.6	70.8	72.3	113.3	117.4	75.3	76.6
SEm±	0.77	0.83	0.71	0.36	1.20	0.48	0.61	0.29
CD (*P*=0.05)	4.66	5.07	4.35	2.17	7.32	2.90	3.73	1.76
Direct effect of P levels								
Control	53.0	59.8	67.5	73.3	113.0	118.5	74.0	76.7
15 kg P/ha	48.5	51.7	60.0	64.7	103.5	108.7	66.0	64.3
15 kg P/ha+PSB	56.5	66.5	72.0	79.7	119.5	120.3	80.5	85.7
30 kg P/ha	42.7	44.8	54.0	54.8	96.0	97	57.5	56.2
SEm±	1.11	1.17	1.23	1.00	1.68	0.69	0.99	0.76
CD (*P*=0.05)	3.41	3.60	3.80	3.09	5.19	2.12	3.04	2.33
Residual effect of NP doses applied to sunflower								
Control	-	57.5	-	70.4	-	113.1	-	73.3
50% RD of NP	-	55.5	-	67.9	-	112	-	70.5
RD of NP	-	54.1	-	66.1	-	108.3	-	68.4
SEm±	-	0.73	-	1.07	-	1.12	-	1.26
CD (*P*=0.05)	-	2.09	-	3.08	-	3.23	-	3.63

SFSI: Sunflower stover incorporation, RD of NP: 80 kg N+15kg P/ha; SFS: sunflower stover; DAS: days after sowing CD: critical differences.

treatments remain statistically at par during both the years. NP doses applied to preceding sunflower had significant residual effect on MBC in soil of succeeding pigeonpea under pigeonpea-sunflower cropping system. MBC in succeeding pigeonpea was higher under the residual effect of RD of NP (80 kg N+15 kg P/ha) over control at all the stages, but remained at par with 50% RD of NP.

Effect of sunflower stover incorporation and nutrient management on soil available nutrients

Available NH_4-N and NO_3-N in soil at different growth stages of pigeonpea

The data on available NH_4-N and NO_3-N in both years (2008 and 2009) are presented in Tables 4 and 5, respectively. Critical appraisal of data reveals that NH_4-N content in soil was higher at earlier stage and decreased over the season due to nitrification process. In contrast, NO_3-N was low in the early stages of growth and gradually buildup towards the end of the season during both year of experimentation. The effect of sunflower stover incorporation was significant at all the growth stages of pigeonpea on NH_4-N and NO_3-N. At 30 and 60 DAS, NH_4-N values were recorded significantly low under sunflower stover incorporation. At 120 DAS and at harvest, the trend was reversed. NO_3-N was markedly lower under sunflower stover incorporation at all the growth stages than no stover incorporation except at harvest during 2008, where statistically similar values were recorded. Different levels of P also had significant influences on both NH_4-N and NO_3-N during both the season. During first year of experimentation (2008), the maximum NH_4-N was recorded with 30 kg P/ha at all the growth stages, which was at par with 15 kg P/ha+PSB and 15 kg P/ha except at harvest stage, where 15 kg P recorded lower values than 30 kg P/ha. In 2009, markedly higher values of NH_4-N were recorded with 30 kg P/ha over the other levels of P, except 120 DAS, where 30 kg P and 15 kg P/ha+PSB was statistically at par.

With regard to NO_3-N, maximum NO_3-N was recorded in control plot followed by 15 kg P/ha. However, lowest values of NO_3-N were recorded with 30 kg P/ha at all the growth stages. Residual effects of NP doses applied to preceding sunflower crop was not found significant on both NH_4-N and NO_3-N in soil of succeeding pigeonpea at all the growth stages.

Table 3. Direct effect of sunflower stover and P management and residual effect of NP on microbial biomass carbon in soil of pigeonpea.

Treatment	Microbial biomass carbon (mg/kg of soil)							
	30 DAS		60 DAS		120 DAS		At harvest	
	2008	2009	2008	2009	2008	2009	2008	2009
Direct effect of SFS management								
Control	116.25	118.75	124.92	128.25	170.58	171.50	210.92	206.75
SFSI @8 t/ha	121.50	129.31	160.25	162.81	194.25	198.06	229.75	237.56
SEm±	1.43	0.75	0.56	0.55	2.37	0.75	0.72	0.51
CD (*P*=0.05)	NS	4.56	3.42	3.32	14.40	4.56	4.36	3.11
Direct effect of P levels								
Control	109.17	119.39	135.00	140.39	175.17	171.39	215.00	215.89
15 kg P/ha	118.50	121.56	137.50	143.56	177.00	183.56	218.50	221.06
15 kg P/ha+PSB	125.33	127.00	149.83	148.00	188.50	193.00	223.33	224.00
30 kg P/ha	122.50	128.17	148.00	150.17	189.00	191.17	224.50	227.67
SEm±	1.78	0.89	1.67	0.82	2.57	0.75	1.87	1.11
CD (*P*=0.05)	5.50	2.75	5.13	2.51	7.91	2.30	5.76	3.43
Residual effect of NP doses applied to sunflower								
Control	-	122.67	-	144.17	-	183.42	-	220.79
50% RD of NP	-	124.00	-	145.50	-	184.75	-	222.13
RD of NP	-	125.42	-	146.92	-	186.17	-	223.54
SEm±	-	0.73	-	0.64	-	0.63	-	0.70
CD (*P*=0.05)	-	2.09	-	1.85	-	1.80	-	2.01

SFSI: Sunflower stover incorporation, RD of NP: 80 kg N+15kg P/ha; SFS: sunflower stover; DAS: days after sowing CD: critical differences.

Available P in soil at different growth stages of pigeonpea

Data pertaining to available P in soil at different growth stages of pigeonpea are presented in Table 6. Perusal of data reveals that available P in soil was recorded significantly higher due to sunflower stover incorporation except 30 DAS, where control was superior. Various P levels increased the available P in soil over the control. Among the different P levels significantly higher values of available P were found with 30 kg P/ha, but it remained consistently at par with 15 kg P/ha+PSB at all the stages during both the crop seasons except at harvest in 2009. At this stage, it was significantly superior over all the P levels. N and P applied to preceding sunflower crop in pigeonpea-sunflower cropping system had a significant residual effect on available P in the soil for succeeding pigeonpea. Residual effect of both doses of NP, that is, 50% RD of NP and RD of NP (80 kg N+15 kg P/ha) increased the available P in soil as compared to control. Highest values of available P were registered with the residual effect of RD of NP (80 Kg N+15 kg P/ha), at initial stage of crop (30 and 60 DAS); it was significantly superior over the residual effect of 50% RD of NP. However, at the latter stages (60 DAS and at harvest) residual effect of RD of NP remained at par with the residual effect of 50% RD of NP.

DISCUSSION

Soil biological properties

The data on microbial activity in terms of dehydrogenase activity, alkaline phosphatase activity and microbial biomass carbon during crop growth period were recorded at 30, 60, 120 DAS and at harvest and presented in Tables 1, 2 and 3, respectively. These activities provide the information on the microbial growth and development. Dehydrogenase activity was chosen as an index of microbial activity as it refers to a group of mostly endo cellular enzymes, which catalyze oxidation of soil organic matter (Pascual et al., 1998). In the present study, higher values of dehydrogenase activity, alkaline phosphatase activity and microbial biomass carbon (at harvest) were observed with sunflower stover incorporation. The lowest values were observed initially and then gradual increase was recorded over the period of growth of crop. All these results suggest that adoption of an organic amendment could lead to an increase in the long term sustainability of soil fertility by improving levels of soil organic matter,

Table 4. Direct effect of sunflower stover and P management on available NH_4-N and NO_3-N (kg/ha) at various stages of pigeonpea in 2008.

Treatment	30 DAS		60 DAS		120 DAS		At harvest	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Direct effect of SFS management								
Control	121.5	44.7	127.9	53.7	89.0	63.1	76.4	67.9
SFSI @8 t/ha	111.4	41.2	112.6	45.0	113.8	45.2	82.2	68.8
SEm±	1.2	0.18	0.70	0.8	0.53	0.25	0.71	0.57
CD (*P*=0.05)	7.3	1.1	4.2	4.9	3.2	1.5	4.3	NS
Direct effect of P levels								
Control	110.3	45.8	114.1	51.4	94.7	57.7	71.4	73.1
15 kg P/ha	115.9	43.3	118.9	50.2	101.1	54.3	77.9	69.5
15 kg P/ha+PSB	118.7	41.6	122.3	48.1	103.9	52.6	82.3	66.2
30 kg P/ha	120.9	41.1	124.2	47.6	105.9	51.9	85.5	64.5
SEm±	1.8	1.0	2.1	0.77	1.98	0.8	1.63	1.00
CD (*P*=0.05)	5.5	3.0	6.5	2.4	6.1	2.6	5.0	3.1

SFSI: Sunflower stover incorporation, RD of NP: 80 kg N+15kg P/ha; SFS: sunflower stover; DAS: days after sowing CD: critical differences.

Table 5. Direct effect of sunflower stover and P management and residual effect of NP on available NH_4- N and NO_3-N (kg/ha) at various stages of pigeonpea in 2009.

Treatment	30 DAS		60 DAS		120 DAS		At harvest	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Direct effect of SFS management								
Control	121.2	45.5	127.9	54.1	89.8	63.8	76.8	68.8
SFSI @8 t/ha	111.2	42.0	113.2	46.4	114.4	45.2	82.8	69.8
SEm±	0.29	0.17	0.64	0.24	0.45	0.26	0.53	0.13
CD (P=0.05)	1.76	1.06	3.89	1.45	2.71	1.56	3.23	0.79
Direct effect of P levels								
Control	110.8	46.8	114.7	53.1	95.6	58.4	72.1	73.9
15 kg P/ha	116.7	43.9	119.7	50.9	101.7	55.0	77.9	70.8
15 kg P/ha+PSB	118.9	42.6	122.2	48.8	104.6	53.2	82.8	67.1
30 kg P/ha	121.5	41.8	125.0	48.3	106.6	52.8	86.4	65.3
SEm±	0.68	0.24	0.74	0.35	1.04	0.23	1.04	0.67
CD (P=0.05)	2.10	0.75	2.29	1.08	3.22	0.71	3.22	2.07
Residual effect of NP doses applied to sunflower								
Control	116.6	44.4	119.2	50.7	101.4	55.4	79.3	70.0
50% RD of NP	116.8	43.8	120.5	50.4	102.0	54.9	79.6	69.4
RD of NP	117.5	43.1	121.3	49.7	102.9	54.2	80.5	68.3
SEm±	0.39	0.43	0.41	0.44	0.53	0.41	0.52	0.52
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

SFSI: Sunflower stover incorporation, RD of NP: 80 kg N+15kg P/ha; SFS: sunflower stover; DAS: days after sowing CD: critical differences.

available nutrients and soil microbial activity (Chander et al., 1998). The organic amendments may supply an additional source of labile carbon and their nutrients to soil for microbial growth and activity (Boggs et al., 2000). Increased dehydrogenase activity, alkaline phosphatase activity and microbial biomass carbon due to application of rice straw compost in rice soil was also reported by Goyal et al. (2009). P levels up to 30 kg P/ha increased the values of dehydrogenase activity and microbial biomass carbon at all the growth stages. Balanced

Table 6. Direct effect of sunflower stover and P management and residual effect of NP on available soil P at different stages of pigeonpea.

Treatment	Available P (kg/ha)							
	30 DAS		60 DAS		120 DAS		At harvest	
	2008	2009	2008	2009	2008	2009	2008	2009
Direct effect of SFS management								
Control	21.98	22.08	19.98	20.06	17.58	17.74	16.30	16.86
SFSI @8 t/ha	20.09	20.16	22.17	22.27	19.73	19.91	18.60	19.10
SEm±	0.29	0.16	0.25	0.27	0.11	0.10	0.11	0.12
CD (P=0.05)	1.74	0.95	1.51	1.64	0.68	0.62	0.68	0.76
Direct effect of P levels								
Control	17.33	17.43	17.17	17.29	17.10	17.27	17.00	17.17
15 kg P/ha	20.50	20.50	20.55	20.65	18.42	18.47	17.35	17.69
15 kg P/ha+PSB	22.77	22.85	22.92	23.00	19.28	19.49	17.55	18.09
30 kg P/ha	23.55	23.70	23.65	23.72	19.82	20.09	17.90	18.98
SEm±	0.76	0.37	0.76	0.40	0.61	0.33	0.16	0.20
CD (P=0.05)	2.35	1.15	2.33	1.23	1.89	1.00	0.48	0.62
Residual effect of NP applied to sunflower								
Control	-	20.53	-	20.55	-	18.15	-	17.68
50% RD of NP	-	21.04	-	21.07	-	18.64	-	18.02
RD of NP	-	21.80	-	21.88	-	19.69	-	18.25
SEm±	-	0.20	-	0.17	-	0.30	-	0.15
CD (*P*=0.05)	-	0.59	-	0.48	-	0.87	-	0.42

SFSI: Sunflower stover incorporation, RD of NP: 80 kg N+15kg P/ha; SFS: sunflower stover; DAS: days after sowing CD: critical differences.

fertilization enhanced the microbial biomass, dehydrogenase activity and phosphatase activity, which may be due to the higher production of organic carbon and P fertilization in particular (Chua et al., 2007). In contrast, alkaline phosphatase activity decreased with increasing the levels of P. Tadano et al. (1993) stated that P cycle enzyme activities are inversely related to P availability and when P is a limiting nutrient, its demand increases resulting in an increase in phosphatase activity. This phenomenon can be explained by a competitive inhibition of phosphatase by phosphate ions or by a negative-feedback of phosphate ions on PHO genes resulting in a repression of phosphatase synthesis by microorganisms (Oshima et al., 1996). These results are in close conformity with the findings of Moscateli et al. (2005) and Bhadoria et al. (2011). Residual effect of NP applied to preceding sunflower up to RD of NP (80 kg N+15 kg P/ha) increased the soil dehydrogenase activity and soil microbial biomass carbon and reduced the alkaline phosphatase activity of succeeding pigeonpea under pigeonpea-sunflower cropping system. This was due to the favourable soil condition and improved soil organic matter due to left over soil nutrients. Improvement in soil biological properties due to the balanced inorganic fertilizer was also recorded by Chu et al. (2005) and Masto et al. (2006).

Available NH_4-N and NO_3-N in soil at different growth stages of pigeonpea

As the experiment proceeded, NH_4-N decreased and NO_3-N increased proportionately. NH_4-N was observed higher at early stage and declined thereafter, whereas there was an inverse trend in NO_3-N, which was lower at earlier stage and increased at harvest stage. Sunflower stover incorporation resulted in the lower values of both NH_4-N and NO_3-N in initial stage up to 60 DAS, after that availability of both NH_4-N and NO_3-N were increased. This might be due to immobilization of mineral nitrogen at initial stage due to sunflower stover incorporation. At later stages, increase in mineral N content was an indicator of release of N from crop residue. Similar findings were also observed by Corbeels et al. (2000), Kachroo et al. (2006) and Shrinivas et al. (2006). P levels have significant influence on both NH_4-N and NO_3-N during both season. Maximum NH_4-N was recorded with 30 kg P/ha at all the growth stages followed by 15 kg P/ha+PSB. However, maximum NO_3-N was recorded in control plot followed by 15 kg P/ha. These variations may be assigned to higher amount of N fixed on account of profused root development and better nodulation under P fertilized plots (Patel, 1980). On the other hand, NO_3-N was higher under control plot due to less N fixation and more nitrification process. Residual effect of NP applied to preceding sunflower crop did not cause any significant difference on both NH_4-N and NO_3-N in soil of succeeding pigeonpea at all the growth stages.

Available P in soil at different growth stages of pigeonpea

Maximum values of available P was observed at 60 DAS there after availability of P in soil decreased. Sunflower stover incorporation caused immobilization of mineral P at initial stage of decomposition and reduced the availability of soil P but in latter stages sunflower stover incorporation caused marked improvement in available P. Similar results were recorded by Sarmah and Bordoloi (1994), Saha et al. (1995) and Lal et al. (2000). It is quite likely as organic additives produce organic acids during the decomposition which increased the availability of phosphorus in soil (Debnath et al., 1991). Various P levels have increased the available P in soil over the control.

Among different P levels, application of 30 kg P/ha and 15 kg P/ha+PSB recorded similar values of available P in the soil at all stages during both the crop seasons. This might be due to increase in amount of root exudates and increased microbial activity leading to greater mineralization of applied and inherent P. Inorganic P is solubilized by the action of organic and inorganic acids secreted by PSB in which hydroxyl and carboxyl groups of acids chelate cations (Al, Fe, and Ca) and decrease the pH in basic soils (Stevenson, 2005). The PSB dissolve the soil P through production of low molecular weight organic acids mainly gluconic and keto gluconic acids (Goldstein, 1995; Deubel et al., 2000). Residual effect of both doses of NP up to RD of P resulted higher availability of soil P as compared to control.

This study suggested that sunflower stover incorporation in pigeonpea under pigeonpea-sunflower cropping system improves the soil health which may enhance the agricultural sustainability. Similarly, application of 30 kg P/ha in pigeonpea was found to be best performing with respect to improving the soil health in terms of biological and chemical properties. Residual effect of RD of NP given to sunflower resulted in better soil health of pigeonpea.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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