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Full Length Article

Comparative Efficacy of Rock Phosphate Enriched Organic Fertilizer *vs.* Mineral Phosphatic Fertilizer for Nodulation, Growth and Yield of Lentil

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Abstract

Optimum impregnation ratio of rock phosphate (RP) and compost in RP-enriched organic fertilizer, its time and rate of application to the crop plants affect the availability of nutrients through the process of mineralization and immobilization. A series of pot and field experiments were conducted to investigate the comparative efficacy of RP-enriched organic fertilizer vs. mineral phosphatic fertilizer on growth, yield and nodulation of lentil. Optimum impregnation ratio of RP and compost and the time of application to improve growth, nodulation and yield of lentil were investigated under wire house conditions. The impregnation ratio of 50:50 RP and compost and time of application of seven days before sowing resulted in the maximum nodulation, growth and yield parameters compared to the other impregnation ratios and the times of application. Optimized impregnation ratio and time of application were further investigated for optimum rate of application under field conditions to enhance nodulation, growth and yield of lentil in comparison with recommended mineral phosphatic fertilizer. The application of RP-enriched organic fertilizer @ 1000 kg ha^{-1} showed an increase of 35.5, 27 and 6% in number of nodules, fresh weight of nodules, and grain yield compared to chemical phosphatic fertilizer, respectively. Similarly, significant increase in P contents of straw and grain was also observed with the application of RP-enriched organic fertilizer @ 1000 kg ha^{-1} compared to chemical phosphatic fertilizer. However, the effect of the application of 800 and 1000 kg ha^{-1} was statistically non-significant for most of the parameters studied. The results suggested that RP-enriched organic fertilizer with optimum impregnation ratio of RP and compost, time of application and rate of application had a pronounced effect on nodulation, growth and yield of lentil as compared to recommended chemical phosphatic fertilizer. © 2015 Friends Science Publishers

Keywords: Phosphorus; Impregnation ratio; Rock phosphate; Time of application; Rate of application; Mineral phosphatic fertilizers; Lentil

Introduction

The organic waste recycling as organic fertilizer for the maintenance of soil health through hygienic methods is vital for sustainable crop production and the welfare of mankind. Addition of organic fertilizer to the soil in the form of compost, farm yard manure, green manure and cereal residues has been well known for improving the physicochemical and biological properties of the soil. It has not only served as source of macro and micro-nutrients for the crop plants but also for the microbes in supporting soil health by serving a quick and easily available source of carbon (Darzi *et al.*, 2012). Energy has been a key limiting factor in getting the maximum crop yields per unit area per unit time. The major advancement in agriculture has been brought about by the use of non-renewable energy sources, the cost of which has risen sharply during the last 2–3 decades and ultimately has increased the prices of chemical phosphatic fertilizers (Meena and Biswas, 2014).

The burning of rural and urban refuse without energy recuperation or their use for land filling are wasteful processes, which should be avoided. On the other hand, composting is a microbiological process for the conversion of organic wastes into a valuable product. It also helps in the reduction of environmental pollution. Moreover, the refuse dumping sites on the outskirts of cities are gradually decreasing due to their massive expansion. Traditional methods of composting have proven unsuitable for the disposal of huge quantities of city wastes. The value of compost not only lies in its macro- and micronutrients but also in its humus contents, which ultimately help in the restoration of soil fertility through the maintenance of organic matter. Addition of organic matter will ultimately help in the restoration of soil fertility (Diaz *et al.*, 1993).

Phosphorus (P) is the second most limiting nutrient element after nitrogen under most of the soil conditions worldwide (Vance *et al.*, 2003). Its availability to the crop plants through the application of chemical phosphatic

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fertilizers is not more than 20%. The situation becomes more adverse in case of leguminous crops, which require more phosphorus compared to the other crops. This has led to the application of phosphatic fertilizers in large amounts than the recommended one and has increased the cost of crop production (Aziz *et al.*, 2006). On the other hand, their application has decreased due to the sky-high prices, scarcity at the right time of application and sub-optimal doses so it has become a burden for the farmers especially living in the developing countries. Another constraint with chemical phosphatic fertilizers is that these are prepared from high quality RP which may be depleted by the year 2050 (Vance *et al.*, 2003). Need of the hour is to find out certain other approaches in order to exploit indigenous rock phosphate resources in bioavailable form without compromising yield.

Rock phosphate is a raw material in the manufacture of chemical phosphatic fertilizers and during the last decade, has been recognized as an important alternative economical source of P for the crops (Reddy *et al.*, 2002). There are many reports about the direct application of RP as a P source to the soils (Chien and Menon, 1995; Akande *et al.*, 2008; Iqbal *et al.*, 2013). From these studies, it has been clearly found that this approach is feasible for the acidic soils having low pH and direct application of RP to the alkaline/calcareous soils as prevailing in Pakistan is not a feasible approach (Caravaca *et al.*, 2004).

There are certain plant growth promoting rhizobacteria (PGPR), which have both 1-aminocyclopropane-1-carboxylate (ACC)-deaminase and P-solubilizing activities. The former reduces the production of stress hormone, the ethylene, by converting its intermediate biosynthesis components into α-ketobutyrate and ammonia (Glick *et al.*, 1998) and the latter increases the availability of fixed P from the RP through the production of organic acids. Higher concentrations (25 $\mu g\ L^{-1}$) of ethylene have been reported to inhibit root growth (Mattoo and Suttle, 1991) and nodulation (Arshad and Frankenberger Jr., 2002). Stimulatory effect on the plant growth of maize and mungbean was reported with the application of bacteria carrying ACC-deaminase activity (Shaharoona *et al.*, 2006). The application of PGPR helps increase the root proliferation, which provides greater surface area to explore more volume of the soils for better uptake of the fixed P (Dey *et al.*, 2004). Microorganisms are involved in a range of processes that affect the transformation of soil P during soil P cycle (Chen *et al.*, 2006). It would be imperative to use the microbes with ACC-deaminase as well as P-solubilizing activity for decreasing the stress hormone, the ethylene, produced during the infection process of nodulation and increasing the availability of P from RP.

Very recently, interest has been renewed in the compost technology. A wise manipulation of the composted material could be to enrich it with RP and PSM, which ultimately reduce its application amount; a laborious part of the process. During composting, most of the organic P in the organic form is converted into inorganic form through mineralization, which ultimately increases the availability of P to the crop plants (Condron *et al.*, 2004). At the same time, certain acids are released during composting which also increase the release of plant available-P from RP. Use of microbial inoculants along with RP-enriched organic fertilizer to prevail over the ecological problems resulting from the loss of plant nutrients and enhancing nutrient use efficiency/nutrient availability could provide sustainable solution for agriculture system. Reports are available on the combined use of RP along with compost and PSM (Saleem *et al.*, 2013; Shahzad *et al.*, 2014); however, no work has been conducted to find out the optimum impregnation ratio of RP and compost, its time and rate of application for the maximum production of crop plants. Keeping in view the above discussion, a series of studies were planned to determine (a) whether or not RP-enriched organic fertilizer is as effective as mineral fertilizer; (b) the optimum impregnation ratio of RP and compost, time and rate of application of RP-enriched organic fertilizer to enhance nodulation, growth and yield of lentil under wire house and field conditions.

Materials and Methods

Preliminary

A series of pot and field experiments were conducted to investigate the optimum impregnation ratio of RP and compost, and the optimum time of application to improve nodulation, growth and yield of lentil. A pre-isolated strain i.e. *Bacillus* spp. strain PSM (previously reported as KAP6) was used in the study. The strain (PSM) had high P-solubilizing (753.0 $\mu g\ mL^{-1}$) and high ACC-deaminase (1.53 $\mu mol\ mL^{-1}$) activities (Baig *et al.*, 2012).

Preparation of RP-enriched Organic Fertilizer

Composting materials consisting of fruit peels and vegetable wastes were collected from the local market of Faisalabad city (longitude 72°0′ and 73°45′ East and 30°30′ and 32°0′ North), Pakistan, oven dried (70°C) for 24 h and ground to fine powder (< 2.0 mm) with the help of electric grinder. The crushed materials were mixed with RP in ratios of 0:100, 25:75, 50:50, 75:25 and 100:0, respectively subjected to composting process in a locally fabricated composter (500 kg capacity) and were continuously run for seven days. Each RP-enriched organic fertilizer with specific ratio was prepared separately after thoroughly removing the first one. The moisture contents were maintained manually (40% v/w). Temperature rose up from 30 to 70°C in the composting unit during 2nd and 3rd day of composting process and then reduced gradually to 30°C after 4th day process. After 7 days, the RP-enriched organic fertilizer produced was subjected to analysis regarding various macronutrients and C/N and C/P ratios were determined.

Similarly, simple compost was also prepared from the crushed materials of fruit peels and vegetable wastes.

Compost and RP-enriched Organic Fertilizer Analysis

The chemical analysis of compost and RP-enriched organic fertilizer before and after the composting was done by using standard methods (Table 1). Carbon content of RP-enriched organic fertilizer was estimated by loss-on-ignition method (Nelson and Sommers, 1999; Ryan *et al.*, 2001). Total nitrogen (N) content was determined by using Kjeldahl distillation apparatus (Jackson, 1962). For phosphorus (P) determination, 1.0 g dried and ground RP-enriched organic fertilizer sample was taken and digested by adding 25 mL of conc. HNO_3 followed by 20 mL of 60% $HClO_4$. After digestion, vanadomolybdo-phosphoric yellow color complex in nitric acid medium was added to the samples and placed for 10 minutes until the color was developed (Jackson, 1973). Then the total P content was determined by taking the reading of absorbance using spectrophotometer (Beckman photometer 1211, London). Moreover, C:P and C:N ratios were also calculated.

Pot Experiments

A pot experiment was conducted to find out the optimum impregnation ratio of RP and compost in RP-enriched organic fertilizer (0:100, 25:75, 50:50, 75:25 and 100:0) to enhance nodulation, growth and yield of lentil under wire house conditions. The trial was conducted in the research area of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan, using completely randomized design (CRD) with six replications. The inoculum of selected strain was prepared by growing in 250 mL Erlenmeyer flask containing National Botanical Research Institute's Phosphate (NBRIP) medium [Glucose, 10.0 g: $Ca_3(PO_4)_2$, 5.0 g; $MgCl_2.6H_2O$, 5.0 g; $MgSO_4.7H_2O$, 0.25 g; KCl, 0.2 g and $(NH_4)_2SO_4$, 0.1 g L^{-1}] (Nautiyal, 1999) for PSM. The flasks were incubated at 28±1°C for 48 h in the orbital shaking incubator (Model OSI-503 LD; Firstek Scientific, Japan) at 180 rev min^{-1}. Rhizobia specific to lentil were kindly provided by the Microbiology Section at Ayub Agricultural Research Institute (AARI), Faisalabad. Lentil seeds were surface sterilized by dipping in 70% ethanol for 2 min and treated with 5% NaClO for 5 min followed by washing 3 times with sterile distilled water. For inoculation, surface sterilized seeds of lentil were coated with suspension of the strain, 15% sugar solution and peat plus clay (1:1 w/w). Control was treated with sterilized peat plus clay containing sterilized broth and sugar solution. Inoculated seeds were placed under shade for drying. For pot experiment, sandy clay loam soil (surface layer 0–15 cm) passed through a 2 mm sieve (40 mesh) was used for filling the pots. Pre-soil analysis regarding physic-chemical properties was done using standard methods described in Hand Book 60 (US Salinity Laboratory Staff, 1954). The soil used in the study was sandy clay loam having pH, 7.6; ECe, 3.4 dS m^{-1}; organic matter, 0.67%; total N, 0.056% and available P, 8.6 mg kg^{-1}. Each pot was filled with 12 kg soil receiving nutrients P and K at the rate of 50 and 25 kg ha^{-1} as single super phosphate and sulphate of potash, respectively. The whole amount of P and K were applied by mixing them uniformly with soil before filling the pots. Four seeds of chickpea were sown in each pot at soil moisture level (water holding capacity) of 70%. One seedling was retained in each pot after germination. For nodulation parameters, three replicates from each treatment (originally six) were harvested at the flowering stage, nodules were excised manually and their fresh and dry weight was recorded using electrical balance. At maturity, agronomic and yield contributing parameters were measured using standard procedures. Grain and straw samples were analyzed for N and P using standard methods of Jackson (1962) and Ryan *et al.* (2001), respectively.

In the second pot experiment, optimum time of application of RP-enriched organic fertilizer (30, 15, 7, 3 and 0 days before sowing) with optimized impregnation ratio of RP and compost i.e. 50:50 was investigated to enhance nodulation, growth and yield of lentil. The trial was conducted under similar environmental condition as stated above. For inoculum preparation and its application methods were the same as described in the above pot experiment. Similar procedures were adopted to quantify the growth, nodulation and yield parameters.

Field Experiment

A field experiment was conducted to evaluate the effectiveness of different application rates (100, 200, 300, 400, 500, 800 and 1000 kg ha^{-1}) of RP-enriched organic fertilizer with optimized impregnation ratio of RP and compost (50:50) and time of application (7 days before sowing) to improve nodulation, growth and yield of lentil as compared to recommended chemical phosphatic fertilizer (60 kg P ha^{-1}). The experiment was conducted in the research area of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan, using randomized complete block design (RCBD) with six replications. The recommended rate of N (25 kg ha^{-1}) and rhizobia were applied in all treatments. For inoculum preparation and its application to the seeds was followed by the methods described earlier. At flowering stage, nodulation parameters were recorded by uprooting ten plants randomly from each replicate plot. Similarly, to quantify the growth and yield parameters at maturity, the whole plot replicate of each treatment was harvested.

Statistical Analysis

The data were subjected to analysis of variance technique (ANOVA) using Statistix v. 8.1 software package (Analytical Software, 2005). The means were compared by least significant difference (LSD) test (Steel *et al.*, 1997).

Results

Nodulation Parameters

The results clearly showed that the impregnation ratio 50:50 of RP and compost and the application time of seven days before sowing significantly increased the number of nodules plant^{-1}, fresh and dry weight of nodules of lentil as compared to the other impregnation ratios and the times of application (Table 2 and 3). The maximum number of nodules plant^{-1} was recorded with the application of 50:50 impregnation ratio of RP and compost (36 number of nodules plant^{-1}) and with the application time of seven days before sowing (35 number of nodules plant^{-1}) while that of the minimum was recorded with the impregnation ratio of 0:100 RP and compost (17 number of nodules plant^{-1}) and with the application time of 30 days before sowing (16 number of nodules plant^{-1}). Similar trend in case of fresh and dry weight of nodules (g) was observed. In case of field experiment, the maximum number of nodules plant^{-1} was recorded with the application of RP-enriched organic fertilizer @ 1000 kg ha^{-1} which was 35.5% more as compared to control (Table 4). The minimum number of nodules plant^{-1} was observed with the application of RP-enriched organic fertilizer @ 100 kg ha^{-1}. Similar trend was observed in case of fresh and dry weight of nodules (g) over control. Data in Table 4 revealed a statistically non-significant effect between the application rate 800 and 1000 kg ha^{-1} regarding nodulation parameters.

Yield Parameters

Growth and yield were significantly improved under different impregnation ratios of RP and compost and under different time of application (Table 2 and 3). The maximum grain yield was recorded with the application of impregnation ratio of 50:50 RP and compost (4.08 g pot^{-1} grain yield) and with the application time of seven days before sowing (4.24 g pot^{-1} grain yield). Similarly, the minimum grain yield was recorded with the application of impregnation ratio of 0:100 RP and compost (0.85 g pot^{-1} grain yield) and with the application time of 0 days before sowing (1.00 g pot^{-1} grain yield). Similar trend was observed in total biomass. Under field conditions, the maximum grain yield was recorded with the application of RP-enriched compost @ 1000 kg ha^{-1} which was 6% more as compared to the control (Table 4). A maximum biological yield (4.74 Mg ha^{-1}) was recorded with the application of RP-enriched organic fertilizer @ 1000 kg ha^{-1}. The effect of the application rate of RP-enriched organic fertilizer @ 1000 and 800 kg ha^{-1} was statistically non-significant regarding most of the growth and yield parameters recorded.

P Content

Data showed that P concentration in straw and grain that the applications of RP-enriched organic fertilizer with impregnation ratio of 50:50 RP and compost and with the application time of seven days before sowing significantly increased the nitrogen content of straw and grain (Table 2 and 3). The maximum P content in straw was recorded with the application RP-enriched organic fertilizer with impregnation ratio of 50:50 RP and compost (0.28% P) and with the application time of seven days before sowing (0.31% P) as compared to other impregnation ratios and the application time. Similar trend was observed in case of the P contents of grains as found in case of P contents in straw. Under field conditions, maximum P content in straw (0.26%) was recorded with the application of RP-enriched organic fertilizer @ 1000 kg ha^{-1} and in case of control (0.26%) set (Fig. 1). Similarly, the maximum P contents in grain as recorded with the application of RP-enriched organic fertilizer @ 1000 kg ha^{-1} which was 12.19% more as compared to the recommended NPK control.

Discussion

In the earlier studies, it has been suggested that the availability of P from low-grade RP could be increased by the combined application of RP and compost (Biswas and Narayanasamy, 2006; Verma *et al.*, 2013). An increase in the P contents of RP-enriched organic fertilizer might be due to the production of organic acids by the microbes and their enzyme activities during the process of composting which decreased the pH of the material being composted and resulted in an increased release of fixed P from RP (Rashid *et al.*, 2004). Previously, it has been reported that extracellular products of the microbial community such as enzymes and chelating agents (organic acids) have substantial effect on the mineralization of organic P present in the compost (Jansson *et al.*, 1988). According to Chien (1979), a lot of CO_2 is produced during composting which after combining with water forms carbonic acids and also helps in the reduction of pH of the materials being composted. This decreased pH would ultimately help solubilize the fixed P in the form of RP or in the soil (Bangar *et al.*, 1989).

Growth and yield parameters were significantly improved, which implied that optimum impregnation ratio and time of application helped in better mineralization of nutrients present in the RP-enriched organic fertilizer, thereby increasing their availability to the crop plants and ultimately improved crop growth and yield. The effect of optimum impregnation ratio and the time of application were enhanced with the application of microbial strain, which possessed high P-solubilizing and ACC-deaminase activities. The ACC-deaminase activity of the PSM used ultimately reduced the ethylene stress and resulted in better root growth, which ultimately helped the plants to explore more soil and to get more nutrients (Shaharoona *et al.*, 2006; Yang *et al.*, 2009; Shahzad *et al.*, 2014).

Table 1: The chemical analysis of the compost and rock phosphate enriched compost (RP-EC)

Parameters	Before composting	After composting				
	Raw organic material	Impregnation ratios of RP and compost, respectively				
		0:100	25:75	50:50	75:25	100:0
Carbon (%)	34.5	25.5	23.7	21.5	17.4	-
Nitrogen (%)	1.38	2.21	1.71	1.53	1.24	-
Phosphorus (%)	0.34	0.45	2.07	2.38	2.15	2.17
C:N	25	11.53	13.85	14.05	14.03	-
C:P	101.47	56.67	11.45	9.03	8.09	-

Table 2: Impact of the application of different impregnation ratios RP and compost in RP-enriched organic fertilizer on no. of nodules plant^{-1}, fresh and dry wt. of nodules (g), grain yield (g pot^{-1}), fresh biomass (g pot^{-1}), P contents in straw and grains (%) of lentil

Impregnation ratio of RP and compost	No. of nodules plant^{-1}	Fresh wt. of nodules (g)	Dry wt. of nodules (g)	Grain yield (g pot^{-1})	Fresh biomass (g pot^{-1})	P in straw (%)	P in grain (%)
0:100†	17 b*	1.47 b	0.32 b	0.85 d	10.4 ab	0.13 ab	0.22 b
25:75	27 ab	1.63 b	0.47 a	1.63 c	11.6 ab	0.14 ab	0.26 ab
50:50	36 a	2.04 a	0.55 a	4.08 a	12.4 a	0.22 a	0.33 a
75:25	27 ab	1.40 b	0.34 b	2.31 b	10.0 b	0.13 ab	0.29 ab
100:0	19 b	1.06 c	0.26 b	0.87 d	6.8 c	0.10 b	0.23 b

* Means followed by the same letters are not statistically different at $P<0.05$ according to least significance difference (LSD) test
† Impregnation ratio

Table 3: Impact of time of application of the optimum ratio of rock phosphate impregnation on no. of nodules plant^{-1}, fresh and dry wt. of nodules (g), grain yield (g pot^{-1}), fresh biomass (g pot^{-1}), P contents in straw and grains (%) of lentil

Time of application	No. of nodules plant^{-1}	Fresh wt. of nodules (g)	Dry wt. of nodules (g)	Grain yield (g pot^{-1})	Fresh biomass (g pot^{-1})	P in straw (%)	P in grain (%)
30†	16 c*	1.74 b	0.31 d	1.04 d	10.6 b	0.16 ab	0.25 b
15	26 b	1.83 b	0.44 b	1.80 c	11.8 a	0.16 ab	0.28 ab
7	35 a	2.14 a	0.52 a	4.24 a	12.5 a	0.23 a	0.34 a
3	26 b	1.67 b	0.36 c	2.52 b	10.3 b	0.16 ab	0.32 a
0	18 c	1.20 c	0.28 d	1.00 d	6.9 c	0.12 b	0.25 b

* Means followed by the same letters are not statistically different at $P<0.05$ according to least significance difference (LSD) test
† Days before sowing

Table 4: Impact of different application rates of RP-enriched organic fertilizer on no. of nodules plant^{-1}, fresh and dry wt. of nodules (g), grain yield (t ha^{-1}) and fresh biomass (t ha^{-1}) of lentil

Rate of application of RP-enriched organic fertilizer (kg ha^{-1})	No. of nodules plant^{-1}	Fresh weight of nodules plant^{-1} (g)	Dry weight of nodules plant^{-1} (g)	Grain yield (t ha^{-1})	Fresh biomass (t ha^{-1})
100†	26 e*	2.28 b	0.48 cd	0.45 e	2.95 d
200	25.7 e	2.50 b	0.45 d	0.55 e	3.13 d
300	32.3 d	2.67 b	0.53 bd	0.63 e	3.57 c
400	38.0 c	2.70 b	0.47 d	0.85 d	3.73 bc
500	43.3 b	2.67 b	0.58 a-c	1.07 c	3.73 bc
800	44.7 ab	2.57 b	0.59 ab	1.15 bc	3.97 b
1000	48.7 a	3.52 a	0.64 a	1.36 a	4.74 a
NPK	46 ab	2.77 b	0.64 a	1.28 ab	4.64 a

* Means followed by the same letters are not statistically different at $P<0.05$ according to least significance difference (LSD) test
† Rate of application of RP-enriched organic fertilizer (kg ha^{-1})

Ethylene is produced under abiotic and biotic stress. The process of infection of rhizobia for nodule formation produces ethylene, which causes stress on the plant root growth (van Workum *et al.*, 1995; Suganuma *et al.*, 1995). The ethylene stress might be neutralized by the application of microbial strain with ACC-deaminase activity. Moreover, the P-solubilizing activity of the strain enhanced the availability of P in the raw P sources i.e. RP to the crop plants, which ultimately resulted in improved nodulation, growth and yield of lentil. Our results showed that a maximum nodulation with the application of RP-enriched organic fertilizer with impregnation ratio of 50:50 RP and compost, application at the time of seven days before sowing and application rate of 1000 kg ha^{-1}. This implies that the PSM inoculation had a positive effect on the nodulation through their P-solubilizing and ACC-deaminase activities. Moreover, plant available P is increased via the production of organic acids and proton extrusion during composting (Surange, 1995) and ethylene stress is reduced through their ACC-deaminase activity (Glick *et al.*, 1998).

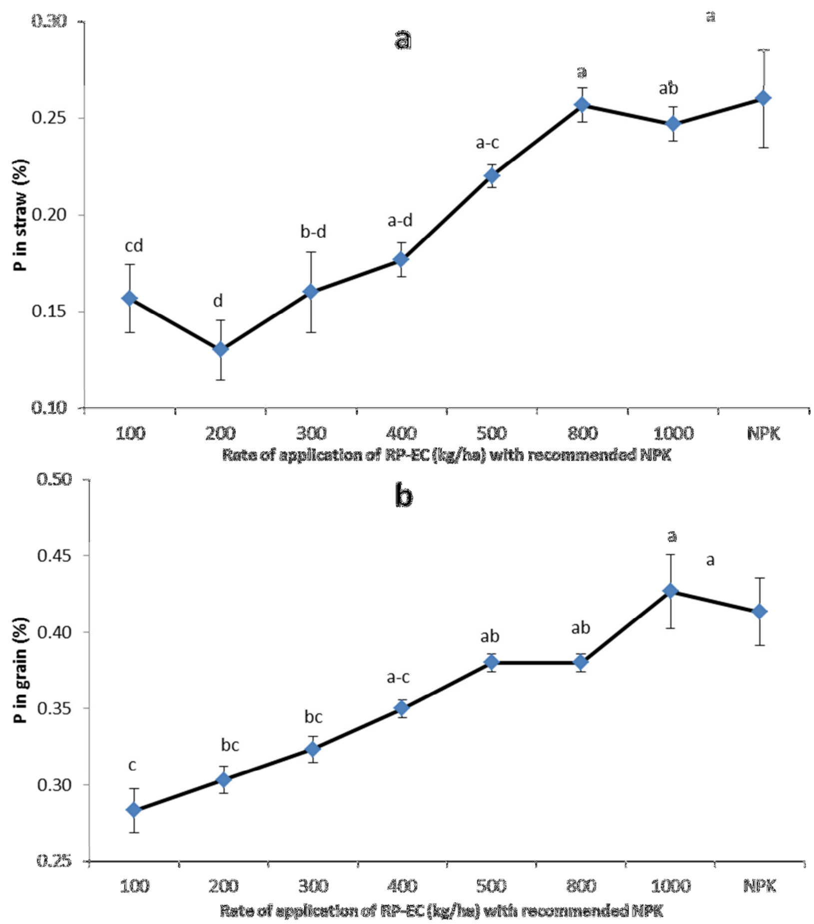

Fig. 1: Impact of rate of application of the optimum ratio and time of rock phosphate impregnation on P (%) in straw (a) and grain (b). Means followed by the same letters are not statistically different at *P<0.05* according to least significance difference

The organic material served as a substrate for the microbial population (Verma *et al.*, 2013). Moreover, the compost also served as nutrient source for the microbes as well as for the crop plants (Chang and Janzen, 1996; Paul and Clark, 1996; Nevens and Reheul, 2003). This premise is supported by the increase in P content of straw and grains of lentil (Table 2 and 3; Fig. 1). Several researchers have found an increase in nodulation in legumes by the inoculation of microbes carrying ACC-deaminase activity (Ma *et al.*, 2004; Shaharoona *et al.*, 2006; Shahzad *et al.*, 2008).

The uptake of P of lentil was also improved, which might be due to an increased availability of P through increased solubilization of RP by the application of PSM and through optimum impregnation ratio of RP and compost. Better root growth to explore more soil and to get more nutrients was observed due to the ACC-deaminase activity of the PSM used (Shaharoona *et al.*, 2006; Yang *et al.*, 2009).

In conclusion, combined application of RP-enriched organic fertilizer with optimum impregnation ratio of RP and compost (50:50), time of application (seven days before sowing) and application rate of RP-enriched organic fertilizer @ 1000 kg ha^{-1} could produce the maximum nodulation, growth and yield parameters of lentil and could provide an economical and sustainable source of P for sustainable agriculture. The results of the application rate of 800 and 1000 kg ha^{-1} were similar so application rate of 800 kg ha^{-1} could be recommended on economical basis. However, multi-sites field trials with optimum rate need to be performed to warrant successful performance in the field.

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