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Bhavya VP
Department of Soil Science and Agricultural Chemistry, University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India

Thippeshappa GN
HOD and Professor, Department of Soil Science and Agricultural Chemistry, University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India

Sarvajna B Salimath
Assistant Professor, Department of Soil Science and Agricultural Chemistry, University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India

Nandish M
Assistant Professor, Department of Agricultural Microbiology, University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India

Sunil C
Assistant Professor, Department of Soil Science and Agricultural Chemistry, University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India

Corresponding Author:
Bhavya VP
Department of Soil Science and Agricultural Chemistry, University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India

Effect of microbial culture on phosphorus release in fly ash amended soil under laboratory incubation study

Bhavya VP, Thippeshappa GN, Sarvajna B Salimath, Nandish M and Sunil C

Abstract
The experiment was carried out to study the effect of microbial culture on phosphorus release in fly ash amended soil. The four levels of fly ash 10, 20, 40, and 80 t ha^{-1} with and without PGPR and *P. straita* were tried in a completely randomized design (CRD) with 13 treatments. Results of laboratory incubation study revealed that higher levels of fly ash with and without PGPR and *P. straita* increased soil pH up to 90 DAI (soil pH was increased from acidic to neutral) except 10, 20, and 30 DAI which showed non-significant. Higher values of available phosphorus were recorded in the treatments that received higher levels of fly ash with PGPR and PSB treatments as compared to the control. However, a significantly higher value of available phosphorus was observed in the treatments T_9 which received Fly ash @ 80 t ha^{-1} + PGPR which found on par with T_{13} (Fly ash 80 t ha^{-1} + *P. straita*) and significantly lower available phosphorus was observed in control where fly ash and P solubilizers were not applied. Under incubation study, the maximum phosphorus fixation capacity of acid soil was observed in the treatment T_1 and lower P fixation capacity was recorded due to the application of a higher dose of fly ash 80 t ha $^{-1}$ with PGPR.

Keywords: Fly ash, pH, available phosphorus and PFC

Introduction

Fly ash is a by-product of the Thermal Power Station (TPS), where coal energy is converted into electrical energy. Its physical and chemical characteristics depend on the composition of parent coal, combustion conditions, the efficiency and type of emission control devices and the disposal methods used (Ram *et al*., 2008) [14].

Fly ash, being an inert material containing mineral nutrients has attracted the agriculture scientists for its utilization to improve crop and soil productivity. It is not only used as a supplemental source of plant nutrients; but, also an amendment for improving acid, alkaline, and degraded soils. Fly ash addition enhanced the physical and chemical properties of acid soils. It optimizes pH value and improves soil aeration, water holding capacity, soil reaction, soil microbial activities, nutrient availability, and plant productivity when applied alone or in combination with organic manure (Sikka and Kansal, 1995) [15].

Phosphorus is deficient in most acid soils, because soluble inorganic P is fixed by Al and Fe. This reaction contributes to less availability of P for crops which is a critical nutritional element in the early stages of plant growth and development. The availability of P is influenced by soil organic matter, pH, and exchangeable and soluble Al, Fe, and Ca. Likewise fly ash has been widely recommended as a soil amendment to acid soil which modifies the physical properties of soil; but, the major concern is the P, which is not in available form.

Fly ash is alkaline in nature which increases the soil pH and neutralizes the acid soils. By application of FA to the acid soils, it neutralizes the soil pH and increases the availability of phosphorus by reducing P with Fe and Al fixation and increase the microbial population (Yeledhalli *et al.*, 2007) [19]. Plant Growth Promoting Rhizobacteria (PGPR) is a group of bacteria that actively colonize plant roots and enhance plant growth and yield. Some common examples of PGPR genera exhibiting plant growth-promoting activity are *Azospirillum*, *P. straita* and *B. mucilaginous* which helps in nitrogen fixation, P-solubilization, and K mobilization respectively and increase nutrient availability Masto *et al.* (2013) [10, 11]. The use of efficient plant growth-promoting rhizobacteria (PGPR) inoculants biofertilizer along with a fly ash would be another sustainable route to increase nutrient availability especially phosphorus which leads to better performance in terms of crop yield. With this view the present investigation was undertaken to study the effect of microbial culture on phosphorus release in fly ash amended soil under laboratory incubation study.

Material and Methods

Laboratory incubation study

An incubation study was carried out during 2019 in the department of Soil Science and Agricultural Chemistry at University of Agricultural and Horticultural Sciences, Shivamogga to study the effect of microbial culture on P release in different levels of fly ash amended soil.

Sample collection

The fly ash used in this experiment was collected from Bellary Thermal Power Station (BTPS), Kudithini, Karnataka.

Methodology

This was a preliminary study conducted to know the extent of the solubility of P by microorganisms in fly ash added to soil. This experiment was done by adding microbial culture ie. *P. straita* and PGPR (Plant growth-promoting activity are *Azospirillum*, *P. straita,* and *Bacillus mucilaginous* which helps in nitrogen fixation, P-solubilization and K mobilization respectively and increase nutrient availability) along with fly ash to high build up soil to know the role of P solubilizer in P solubility and available P in the acid soil. Two kilo gram of soil was filled in separate plastic boxes (2 kg capacity) and treatments were imposed as per the following treatment details and replicated thrice and was laid out in a completely randomized design (CRD). With two basic objectives, an incubation study was conducted.

1. To study the effect of different levels of fly ash with and without PGPR and *P. straita* on pH of acid soil.
2. To know the effect of different levels of fly ash with and without PGPR and *P. straita* on available phosphorus of acid soil.

Experimental details

Design: CRD (completely randomized design)
Treatments: 13
Replications: 3
Fly ash levels: 04 (10, 20, 40, and 80 t ha^{-1})

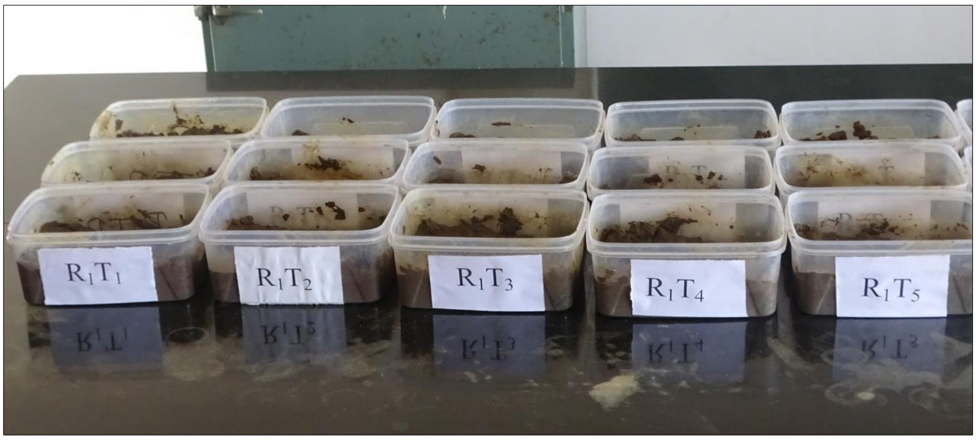

Plate 1: An over view of incubation study on P release pattern in acid soil due to fly ash with and without PGPR application

Treatment details

T_1: Control (RDF + FYM)
T_2: Fly ash @10 t ha^{-1}
T_3: Fly ash @20 t ha^{-1}
T_4: Fly ash @40 t ha^{-1}
T_5: Fly ash @80 t ha^{-1}
T_6: Fly ash @10 t ha^{-1} + PGPR
T_7: Fly ash @20 t ha^{-1} + PGPR
T_8: Fly ash @40 t ha^{-1} + PGPR
T_9: Fly ash @80 t ha^{-1} + PGPR
T_{10}: Fly ash @10 t ha^{-1} + *P. straita*
T_{11}: Fly ash @20 t ha^{-1} + *P. straita*
T_{12}: Fly ash @40 t ha^{-1} + *P. straita*
T_{13}: Fly ash @80 t ha^{-1} + *P. straita*

Note: Recommended dose of FYM was added commonly to all the treatments

Analysis of soil samples for soil pH, available phosphorus, and P fixation capacity

Soil reaction (pH)

Soil pH was determined in 1:2.5 soil-water suspension by using a combination electrode in a pH meter (Jackson 1973) [7].

Available phosphorus

Available phosphorus was extracted with Bray 1 solution in the case of acid soils and Olsen's extractant in the case of neutral and alkaline soils; the P in the extractant was estimated by the Chloro-molybdophosphate method by using ascorbic acid as the reluctant. The intensity of blue colour was read at 660 nm using (Systronics Visiscan 167) spectrophotometer (Bray and Kurtz, 1945; Olsen *et al*., 1954) [1, 13].

Phosphorus fixation capacity

Phosphorus fixation at different levels of added P was determined by the method of Ghosh *et al.* (1983) [5]. Two grams of soil was weighed in separate 100 ml conical flasks. The soil was brought to one corner of the flask and 2 ml each of 17.5, 35, 70, 140, 280, 420, 560, and 700 ppm P solutions were added separately to each flask in the form of KH_2PO_4. The flasks were plugged with cotton wool and incubated for 96 h at room temperature. A control was also taken simultaneously. After 96 h, 1 g charcoal and 40 ml of 0.5 M $NaHCO_3$ solution were added and shaken for 1 hour. In acid soil, Bray and Kurtz reagent (0.03 NNH_4F in 0.025 N HCl) was added for the extraction of P. After filtration through Whatman No. 40 filter paper, 5ml of the filtrate was taken in 25 ml volumetric flask and phosphorus content was measured. The P concentration in 0 ppm P addition treatment was subtracted from those of samples of other P addition rate treatments to correct for P originally present. The amounts of added P recovered from the soil samples were then calculated. Phosphorus fixing capacity, denoted by percent phosphorus fixation was calculated by statistical analysis as given below Ghosh *et al.* (1983) [5].

$$PFC = \frac{C-(B-A)}{C} \times 100$$

Where,
A = Initial content in the soil
B = P content in the test samples
C = P added to the soils

III. Results and Discussion

The results obtained on various aspects like soil pH, P fixation capacity, and available phosphorus which were obtained from the present investigation are briefly discussed under the following headings.

Effect of different levels of fly ash on pH of acid soil at different days of incubation periods

Application of higher levels of fly ash with and without PGPR and *P. straita* increased soil pH up to 90 DAI except 10, 20, and 30 days after incubation (DAI) which showed non-significant (Table 1).

At 40 and 50 DAI, a significantly higher soil pH was observed in the treatment T_9 (Fly ash 80 t ha^{-1} + PGPR) with 5.90 and 6.01, respectively which found on par with T_{13} (5.88 and 6.00, respectively), T_5 (5.87 and 5.99, respectively), and followed by treatment T_7 (Fly ash 20 t ha^{-1} + PGPR) which recorded 5.81 and 5.90, respectively. A significantly lower value of soil pH was recorded in the control treatment (5.62 and 5.64, respectively) where fly ash and P solubilizer were not applied.

Among different treatments at 60 and 70 DAI, T_9 (Fly ash 80 t ha^{-1} + PGPR) showed significantly higher soil pH which noticed 6.16 and 6.24, respectively which remained statistically on par with the values of 6.14 and 6.23 respectively of T_{13} (Fly ash 80 t ha^{-1} + *P. straita*), T_5 (6.11 and 6.21, respectively) and followed by treatment T_7 (Fly ash 20 t ha^{-1} + PGPR) which recorded 6.01 and 6.14, respectively which were highly superior over other treatments. Treatment T_1 recorded a significantly lower value of soil pH (5.68 and 5.70, respectively).

A similar trend was observed in the variation of soil pH at 80 DAI. At 80 DAI, among the treatments applied, T_9 (Fly ash 80 t ha^{-1} + PGPR) recorded the highest soil pH value of 6.36 which found on par with T_{13} treatment (Fly ash 80 t ha^{-1} + *P. straita*) with 6.34, T_5 (6.46) and followed by treatment T_7 (Fly ash 20 t ha^{-1} + PGPR) which recorded 6.26, respectively which were highly superior over other treatments. A significantly lower value of soil pH was recorded in control treatment with 5.71 where only farm yard manure (FYM) and recommended dose of fertilizer (RDF) were added.

Even at 90 DAI, T_9 treatment (Fly ash 80 t ha^{-1} + PGPR) showed significantly higher soil pH with 6.49 which found on par with T_{13} treatment (Fly ash 80 t ha^{-1} + *P. straita*) with 6.47, T_5 (6.46) and followed by treatment T_7 (Fly ash 20 t ha^{-1} + PGPR) which recorded 6.37, respectively which were highly superior over other treatments. A significantly lower value of available phosphorus was recorded in the control treatment (5.73).

There was an increase in pH of acid soil at all levels of fly ash with or without PGPR application as the days of period increased. The increase in pH of acid soil with fly ash application was mainly attributed to the high pH of fly ash (8.22) with the dominant composition of alkaline carbonates and alkali earth metals. As fly ash applied to the acid soil, it releases alkaline compounds present in fly ash, which might have neutralized the soil acidity and thus increased the soil pH to neutral. The fly ash also contain a significant quantity of Ca, it reacts with H^+ and monomeric Al species and replaced the monomeric Al and H^+ species from soil exchange complex in acidic soil thus alleviate soil pH (Tripathy *et al.*, 2005) [18].

Another possible reason for the increase in soil pH might be due to the neutralization of H^+ by alkali salts and also due to the solubilization of basic metallic oxides of fly ash in the soil. Khan and Khan (1996) [8] and Chang *et al.* (2007) [2] revealed that increased in soil pH from 5.7 to 6.2 due to fly ash application and thus it indicated that the Ca^{2+} content of the fly ash was the primary factor and the neutralizing capacity is the second factor for increased soil pH.

Table 1: Effect of different levels of fly ash on pH of acid soil at different days of incubation periods

Treatment details	Soil pH								
	10 DAI	20 DAI	30 DAI	40 DAI	50 DAI	60 DAI	70 DAI	80 DAI	90 DAI
T_1: Control (RDF + FYM)	5.55	5.58	5.60	5.62	5.64	5.68	5.70	5.71	5.73
T_2: Fly ash @10 t ha^{-1}	5.59	5.64	5.68	5.74	5.81	5.86	6.00	6.14	6.27
T_3: Fly ash @20 t ha^{-1}	5.62	5.67	5.70	5.79	5.88	5.96	6.11	6.23	6.34
T_4: Fly ash @40 t ha^{-1}	5.66	5.69	5.76	5.84	5.96	6.08	6.18	6.30	6.43
T_5: Fly ash @80 t ha^{-1}	5.67	5.72	5.79	5.87	5.99	6.11	6.21	6.33	6.46
T_6: Fly ash @10 t ha^{-1} + PGPR	5.60	5.65	5.71	5.76	5.83	5.90	6.05	6.18	6.30
T_7: Fly ash @20 t ha^{-1} + PGPR	5.61	5.66	5.74	5.81	5.90	6.01	6.14	6.26	6.37
T_8: Fly ash @40 t ha^{-1} + PGPR	5.65	5.71	5.78	5.86	5.98	6.10	6.20	6.32	6.45
T_9: Fly ash @80 t ha^{-1} + PGPR	5.68	5.73	5.81	5.90	6.01	6.16	6.24	6.36	6.49
T_{10}: Fly ash @10 t ha^{-1} + *P. straita*	5.59	5.64	5.70	5.75	5.82	5.88	6.03	6.15	6.28
T_{11}: Fly ash @20 t ha^{-1} + *P. straita*	5.63	5.68	5.73	5.80	5.89	5.97	6.12	6.24	6.35
T_{12}: Fly ash @40 t ha^{-1} + *P. straita*	5.66	5.70	5.77	5.85	5.97	6.09	6.19	6.31	6.44
T_{13}: Fly ash @80 t ha^{-1} + *P. straita*	5.67	5.72	5.80	5.88	6.00	6.14	6.23	6.34	6.47
S.Em±	0.04	0.05	0.07	0.011	0.017	0.022	0.014	0.011	0.015
C. D. at 1%	NS	NS	NS	0.03	0.05	0.06	0.04	0.03	0.04

RDF: Recommended dose of fertilizer, **PGPR:** Plant growth promoting rhizobacteria, **FYM:** Farm yard manure, **DAI:** Days after incubation
Note: FYM is common to all the treatments

Effect different levels of fly ash on available phosphorus status of soil at different days of incubation periods

The results on available phosphorus in acid soil at different days of incubation study are presented in Table 2.

Available phosphorus was highly increased in all the days of the incubation study due to the application of fly ash with

PGPR and *P. straita* up to 90 DAI except 10, 20, and 30 DAI which showed non-significant. Higher values of available phosphorus were recorded in the treatments that received higher levels of fly ash with PGPR and PSB treatment as compared to control where no fly ash was applied. There was slight increase available phosphorus in acid soil and no significant effect was found due to the application of fly ash with PGPR and PSB as compared to the application of fly ash as alone.

At 40 and 50 DAI, a significantly higher value of available phosphorus was observed in the treatments T_9 which received Fly ash 80 t ha^{-1} + PGPR with 53.79 and 54.94 kg ha^{-1}, respectively which found on par with T_{13} (50.89 and 51.97 kg ha^{-1}, respectively), T_5 (48.53 and 49.66 kg ha^{-1}, respectively) and followed by treatment T_7 (Fly ash 20 t ha^{-1} + PGPR) which recorded 40.88 and 41.75 kg ha^{-1}, respectively. A significantly lower value of available phosphorus was recorded in the control treatment (21.71 and 22.7 kg ha^{-1}, respectively) where fly ash and P solubilizer were not applied. It was noticed from the results presented in Table 2 that the available P was significantly increased due to the application of fly ash with P solubilizers compared to control at 60 and 70 DAI. Among different treatments, T_9 (Fly ash 80 t ha^{-1} + PGPR) showed significantly higher available phosphorus content which noticed 57.23 and 59.75 kg ha^{-1}, respectively which remained statistically on par with the values of 54.14 and 56.16 kg ha^{-1} respectively, of T_{13} treatment (Fly ash 80 t ha^{-1} + *P. straita*), T_5 (51.62 and 54.59 kg ha^{-1}, respectively) and followed by treatment T_7 (Fly ash 20 t ha^{-1} + PGPR) which recorded 43.49 and 44.28 kg ha^{-1}, respectively which were highly superior over other treatments. Treatment T_1 recorded a significantly lower value of available phosphorus content (23.09 and 25.18 kg ha^{-1}, respectively).

Table 2: Effect of different levels of fly ash on available P_2O_5 status of acid soil at different days of incubation

Treatment details	Available P_2O_5 (kg ha^{-1})								
	10 DAI	**20 DAI**	**30 DAI**	**40 DAI**	**50 DAI**	**60 DAI**	**70 DAI**	**80 DAI**	**90 DAI**
T_1: Control (RDF + FYM)	19.58	20.36	21.15	21.71	22.17	23.09	25.18	26.59	28.29
T_2: Fly ash @10 t ha^{-1}	19.66	20.45	21.23	25.70	26.24	27.34	31.42	33.18	35.30
T_3: Fly ash @20 t ha^{-1}	19.98	20.78	21.58	36.50	37.28	38.83	39.60	41.83	44.50
T_4: Fly ash @40 t ha^{-1}	22.26	23.15	24.04	43.10	44.02	45.86	47.47	50.14	53.34
T_5: Fly ash @80 t ha^{-1}	23.14	24.07	24.99	48.53	49.56	51.62	54.59	57.66	61.34
T_6: Fly ash @10 t ha^{-1} + PGPR	19.88	20.68	21.47	34.12	34.85	36.30	35.64	37.64	40.05
T_7: Fly ash @20 t ha^{-1} + PGPR	22.10	22.98	23.87	40.88	41.75	43.49	44.28	46.76	49.75
T_8: Fly ash @40 t ha^{-1} + PGPR	22.42	23.32	24.21	47.21	48.21	50.22	53.42	56.42	60.02
T_9: Fly ash @80 t ha^{-1} + PGPR	23.82	24.77	25.73	53.79	54.94	57.23	59.75	63.11	67.14
T_{10}: Fly ash @10 t ha^{-1} + *P. straita*	19.74	20.53	21.32	29.28	29.9	31.15	35.08	37.05	39.42
T_{11}: Fly ash @20 t ha^{-1} + *P. straita*	21.88	22.76	23.63	37.55	38.35	39.94	41.34	43.66	46.45
T_{12}: Fly ash @40 t ha^{-1} + *P. straita*	22.68	23.59	24.49	46.24	47.23	49.19	49.81	52.61	55.97
T_{13}: Fly ash @80 t ha^{-1} + *P. straita*	23.54	24.48	25.42	50.89	51.97	54.14	56.16	59.32	63.11
S.Em±	1.43	1.49	1.56	2.23	2.30	2.39	2.43	2.57	2.73
C. D. at 1%	NS	NS	NS	6.59	6.78	7.05	7.18	7.59	8.04

RDF: Recommended dose of fertilizer, **PGPR:** Plant growth promoting rhizobacteria, **FYM:** Farm yard manure, **DAI:** Days after incubation
Note: FYM is common to all the treatments

A similar trend was observed in the variation of available P status at 80 DAI. At 80 DAI, among the treatments applied, T_9 (Fly ash 80 t ha^{-1} + PGPR) recorded the highest available P value of 63.11 kg ha^{-1} which found on par with T_{13} treatment (Fly ash 80 t ha^{-1} + *P. straita*) with 59.32 kg ha^{-1}, T_5 (57.66 kg ha^{-1}) and followed by treatment T_7 (Fly ash 20 t ha^{-1} + PGPR) which recorded 46.76 kg ha^{-1}, respectively which were highly superior over other treatments. A significantly lower value of available phosphorus was recorded in control treatment with 26.59 kg ha^{-1} where only FYM and RDF were added.

Even at 90 DAI, T_9 treatment (Fly ash 80 t ha^{-1} + PGPR) showed significantly higher available phosphorus content in the soil which noticed 67.14 kg ha^{-1} which found on par with T_{13} treatment (Fly ash 80 t ha^{-1} + *P. straita*) with 63.11 kg ha^{-1}, T_5 (61.34 kg ha^{-1}) and followed by treatment T_7 (Fly ash 20 t ha^{-1} + PGPR) which recorded 49.75 kg ha^{-1}, respectively which were highly superior over other treatments. A significantly lower value of available phosphorus was recorded in the control treatment (28.29 kg ha^{-1}).

Application of fly ash with PGPR and *P. straita* significantly increased available phosphorus content in acid soil as compared to other treatments. The possible mechanism for increased P_2O_5 availability with fly ash application in soil could be attributed to the release of alkaline compounds from fly ash, which neutralized the soil acidity and thus increased the soil pH and it is ameliorator of P complexing metals (Al^{3+}, Fe^{3+}), promoter of microbial activity which helps in hastening P mineralization. Thus increases the available P_2O_5 content with fly ash addition.

As fly ash contains a significant quantity of Ca, it can replace the monomeric Al species from soil exchange complex in acidic soil and increases the availability of P_2O_5 by reducing the P fixation. The favourable effect of fly ash on phosphorus availability was also reported by Matte and Kene (1995) [12] and Lee *et al.* (2004) [9]. This indicates that the neutralizing effect of the alkali fly ash in acidic soil is a very important factor for increased P availability during rice cultivation.

Application of PGPR along with fly ash enhances the availability of P_2O_5 by mineralizing organic P in soil and by solubilizing the precipitated phosphate (Yong *et al.* 2007) [20]. The P solubilizing bacteria (PSB) helps in realizing phosphorus from native as well as protecting the fixation of added phosphate and render P more available for the plants leading to increased P content. Similar findings were reported by Chang *et al.* (2007) [2], Gaind and Gaur (2002) [4] and Duarah *et al.* (2011) [3]. Also, the high Si content of fly ash might affect increasing available-P concentration in soil. Silicate ions enhance the solubility of P in soil ion by displacing P from ligand exchange sites (Gourab and Joy, 2011) [6] and by inhibiting P ion sorption for the same specific anion exchange site.

Effect of different levels of fly ash on phosphorus fixation capacity (PFC) of soil

Results on phosphorus fixation capacity of acid soil and available phosphorus content as influenced by the addition of higher levels of fly ash with and without PGPR and *P. straita* are presented in Table 3. The higher phosphorus fixation capacity was observed in the treatment where only FYM and RDF were added as compared to fly ash application with P solubilizers. Average phosphorus fixing capacity (PFC) was varied from 38.4 to 59.90 percent in soils of different treatments. Higher phosphorus fixation capacity (59.90%) was observed in treatment T_1 which received only FYM and RDF and followed by the treatment T_2 with 51.73 per cent (Fly ash 10 t ha^{-1}). Lower P fixation capacity was recorded in the treatment T_9 (38.40%) which received Fly ash 80 t ha^{-1} + PGPR, T_{13} (39.99%) and T_5 (40.79%) and followed by the treatment T_8 (Fly ash 40 t ha^{-1} + PGPR) (41.29%) as compared to control treatment (59.90%).

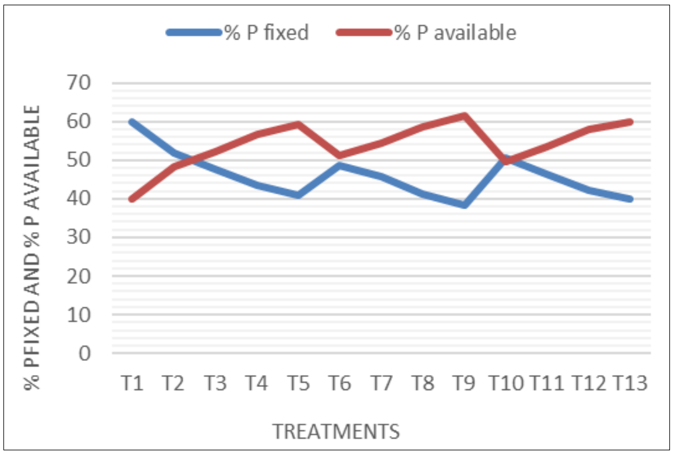

Fig 1: Effect of fly ash and PGPR on percent P fixed and percent P available in acid soil under incubation study.

Maximum available phosphorus was observed in the treatment T_9 (Fly ash 80 t ha^{-1} + PGPR) 61.60 per cent and T_{13} (60.01%) and T_5 (59.21%). Lower available phosphorus was noticed in control treatment where fly ash and P solubilizers were not applied (T_1: 40.10%).

Phosphorus availability mainly depends on soil pH. The highest P fixation capacity was observed in T_1 treatment (RDF + FYM) may be due to, at low pH the presence of more amounts of free iron oxides and low availability of phosphorus in soils can be found mainly due to the sorption of phosphorus on the active surfaces of aluminum and iron oxides and clay minerals. At low pH, phosphate formation was more, maybe due to the presence of iron and aluminium which resulted in the precipitation of insoluble iron and aluminium phosphates (Dao *et al.*, 2001). Another possible mechanism for the low availability of P in acid soil might be due to a major portion of the added P through fertilizers and manures got fixed by the Fe (III) and Al oxides due to their soluble form. Since applied fertilizer, readily reacts with ferric hydroxides, leading to the conversion of water-soluble form to insoluble form (Singaram and Kothandaraman, 1991).

The increased P availability is probably due to the neutralization of soil acidity by the alkali oxides present in the fly ash. At neutral pH, the availability of P will be more due to the suppression of the activity of potential Fe and Al ions that are responsible for P fixation in soils and P fixing capacity of the fly ash-soil mixture decreased due to the interaction between them. The availability of Al^{3+} / Fe^{3+} and Ca^{2+} is one of the prerequisites for P fixation; in general, all of these ions will be suppressed at neutral pH. Simian results were reported by Masto *et al.* (2013) [10, 11].

Application of higher dose of fly ash along with PGPR and *P. straita* enhanced the availability of P_2O_5 by mineralizing organic P in soil and solubilizing the precipitated phosphate (Yong *et al.* 2007) [20]. The P solubilizing bacteria (PSB) helps in realising P from native as well as protecting the fixation of added phosphate and render P more available for the plants leading to increased P content. Similar findings were reported by Chang *et al.* (2007) [2], Gaind and Gaur (2002) [4], and Duarah *et al.* (2011) [3]. The organic matter might have increased the solubility of phosphate in soils. The organic anions compete with phosphate ions for the binding sites on the soil particles or these anions may chelate with aluminium, iron, and calcium and thus decrease the phosphate-precipitating power of these cations. Similar findings were reported by Lee *et al.*, (2004) [9].

Table 3: Effect of different levels of fly ash and PGPR on phosphorus fixation capacity in fly ash amended soil

Treatment details	% P fixed	% P available
T_1: Control (RDF + FYM)	59.90	40.10
T_2: Fly ash @10 t ha^{-1}	51.73	48.27
T_3: Fly ash @20 t ha^{-1}	47.80	52.20
T_4: Fly ash @40 t ha^{-1}	43.38	56.62
T_5: Fly ash @80 t ha^{-1}	40.79	59.21
T_6: Fly ash @10 t ha^{-1} + PGPR	48.70	51.30
T_7: Fly ash @20 t ha^{-1} + PGPR	45.60	54.40
T_8: Fly ash @40 t ha^{-1} + PGPR	41.29	58.71
T_9: Fly ash @80 t ha^{-1} + PGPR	38.40	61.60
T_{10}: Fly ash @10 t ha^{-1} + *P. straita*	50.4	49.60
T_{11}: Fly ash @20 t ha^{-1} + *P. straita*	46.52	53.48
T_{12}: Fly ash @40 t ha^{-1} + *P. straita*	42.11	57.89
T_{13}: Fly ash @80 t ha^{-1} + *P. straita*	39.99	60.01

Conclusion

Fly ash is alkaline in nature which increases the soil pH. By application of FA to the acid soils, it neutralizes the soil pH and increases the availability of phosphorus by reducing P with Fe and Al fixation. The use of efficient plant growth-promoting rhizobacteria (PGPR) and treatments along with fly ash would be another sustainable route to increase nutrient availability especially phosphorus which leads to better performance in terms of crop yield. The laboratory incubation study revealed that the application of higher levels of fly ash (80 t ha $^{-1}$) with PGPR and *P. straita* showed higher phosphorus availability, soil pH and less P fixation capacity in acid soil as compared to fly ash alone and control.

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