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Influence of fly ash on physical and chemical properties of acid soil

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Abstract
The field experiment was conducted at Agricultural and Horticultural Research Station (AHRS), Bhavikere under UAHS, Shivamogga to study the effect of different levels of fly ash on physical and chemical properties of soil. The four levels of fly ash 10, 20, 30 and 40 t ha^{-1} with and without Plant Growth Promoting Rhizobacteria were tried with ten treatments. The effect of fly ash and their combination with and without Plant Growth Promoting Rhizobacteria showed a non-significant effect on bulk density, particle density and EC. A higher dose of fly ash 40 t ha^{-1} recorded significantly higher maximum water holding capacity (35.05%), porosity (59.41%), organic carbon (5.54 g kg^{-1}) and increased the pH of acid soil to near neutral (6.38) over control from 30 to 90 days after planting. Fly ash 40 t $dddha^{-1}$ with Plant Growth Promoting Rhizobacteria significantly increased the availability of macro and micro nutrients as compared to control.

Keywords: Soil, Fly ash, physical Bulk density, particle density, organic carbon, maximum water holding capacity and chemical properties macro and micro nutrients

Introduction
Fly ash is a by-product of the Thermal Power Station (TPS), where coal energy is converted into electrical energy. Fly ash is an amorphous mixture of ferroaluminosilicate minerals generated from the combustion of coal at a temperature of 400 to 1500 ^{0}C Sharma and Kalra (2006) [28, 29]. 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 (Carlson and Adriano., 1993) [7].

Fly ash is generally of silt loam texture with the diameter of the particle of less than 0.010 mm and fly ash has the pH value ranges from 6 to 11, electrical conductivity (EC) of 42 to 450 μ Scm^{-1}. Most of the fly ash has the bulk density (BD) values less than 1 g cm^{-3} and water holding capacity ranges from 43 to 66 percent. Chemically fly ash is a ferro-aluminosilicate mineral, contains various major secondary, and trace elements (Aggarwal *et al*., 2009) [1]. Total major nutrients like N and P are low *i.e.* 0.056 and 0.087 percent, respectively, but it contains a sufficiently higher amount of total K (0.172%), CaO (1.60%), MgO (0.96%), and total trace elements *i.e.* Mn (3.98 ppm), Cu (3.60 ppm), Zn (1.30 ppm) and Fe (3.81 ppm) (Bhoyer, 1998) [5].

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 is found to improve permeability status, reduces bulk density, 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) [31].

Fly ash, with its abundant availability and remarkable ameliorative and nutritive properties, warrants an eco-friendly approach to be used as a soil amendment. Fly ash may be used in plant growth and soil reclamation but scientific research is certainly necessary to model the concentration-uptake-dose-response functions between the amended medium and plants (Jala and Goyal, 2006; Ritchey *et al*., 2012) [15, 24].

Fly ash is alkaline in nature which increases the soil pH and neutralizes the acid soils. By application of FA to the acid soils, improves physical properties (MWHC, BD, etc.), neutralizes the soil pH and increases the availability of phosphorus by reducing P with Fe and Al fixation and increase the microbial population.

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. 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.

By knowing all the beneficial effects of fly ash on acid soil, a field experiment was conducted in the southern transition zone of Karnataka on acid soil with the objective to know the effect of fly ash on physical and chemical properties of soil.

Materials and Methods

The present investigation entitled 'Studies on influence of fly ash on properties of acid soil under rice crop (Varity Jyothi) in southern transition zone of Karnataka' was carried out during 2019 at AHRS, Bavikere.

Location of the field experimental site

The experiment was conducted at Agricultural and Horticultural Research Station (AHRS), Bhavikere under UAHS, Shivamogga.

Field experimental details

The field experiment was planned with ten treatments consisting of four levels of fly ash at 10, 20, 30 and 40 t ha^{-1}. The farmyard manure (FYM) and recommended dose of fertilizer (RDF) were applied commonly to all the treatments. The treatments were imposed in RCBD design with three replications for each treatment. The rice variety Jyothi was taken as a test crop. The treatment details are as follows.

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 30 t ha^{-1}
T_5: Fly ash 40 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 30 t ha^{-1} + PGPR
T_9: Fly ash 40 t ha^{-1} + PGPR
T_{10}: T_1 + PGPR

Note: FYM: Farm yard manure (10 t ha^{-1})
RDF: Recommended dose of fertilizer (100:50:50 kg ha^{-1})
PGPR: Plant growth promoting rhizobacteria
Recommended dose of N: P_2O_5: K_2O (100:50:50) and FYM 10 t ha^{-1}were applied for all the treatments.

Land preparation and imposition of treatments

The experimental plot was ploughed with tractor-drawn cultivator and brought to a fine tilth by harrowing twice and weeds were removed from the experimental site. The experiment was laid out in flat beds and individual plots of 3.6 m × 3.0 m and small bunds of 30 cm were raised around each plot and levelled within the plots. A channel between replications was prepared and the same was used for irrigation. The fly ash and FYM were applied to the soil according to treatment details 30 days and 25 days before transplanting, respectively. The recommended dose of phosphorus and potassium were applied as DAP and muriate of potash during the transplanting time and 50 percent of recommended nitrogen was supplied through DAP and urea at the time of transplanting, remaining dose (50%) at the tillering stage through urea was applied. The rice seedlings were transplanted in each plot with a spacing of 30 cm in between the rows and 10 cm in between the plants. Weeding and intercultural operation were taken up as per the package of practices.

Design : RCBD
Treatments : 10
Replication : 3
Gross plot size : 3.6 m × 3.0 m
Crop : Rice
Variety : Jyothi
Spacing : 30 cm ×10 cm
RDF : 100:50:50 kg N: P_2O_5: K_2O ha^{-1}

Methods of soil analysis

Soil analysis was done for all macro and micro nutrients by using following methods

Table 1: Methods followed for the analysis of Soil

Sl. No.	Parameters	Methods	References
1.	pH	Potentiometry	Jackson (1973) [14]
2.	EC (dSm^{-1})	Conductometry	Jackson (1973) [14]
3.	Bulk density (Mg m^{-3})	Core sampler method	Black (1965) [6]
4.	MWHC (%)	Keen Rackzowski method	Baruah and Barthakur (1997) [3]
5.	Organic carbon (g kg^{-1})	Walkley and Black wet oxidation method	Walkely and Black, 1934 [34]
6.	Nitrogen (%)	Kjeldahl digestion- distillation method	Piper (1996)
7.	Phosphorus (%)	Vanadomolybdate yellow color method	Piper (1996)
8.	Potassium (%)	Flame photometer method	Piper (1996)
9.	Calcium (%)	Complexometric titration method	Baruah and Barthakur (1997) [3]
10.	Magnesium (%)	Complexometric titration method	Baruah and Barthakur (1997) [3]
11.	Sulphur (%)	Turbidimetry method	Black (1965) [6]
12.	Iron (mg kg^{-1})	Atomic Absorption Spectrophotometry method using the appropriate method	Lindsay and Norwell (1978) [18]

Initial soil characteristics of the experimental site

Initial characterization of the soil of the experimental site indicated that soil had a bulk density of 1.61 Mg m^{-3}, maximum water holding capacity (23.52%), and pH of 5.57, EC of 0.28 dSm^{-1} with the organic carbon content of 4.19 g kg^{-1} and the texture of soil was sandy loam. Further, the soil was low in nitrogen (234.18 kg ha^{-1}), high in available phosphorus status (35.16 kg ha^{-1}) and available potassium content was 114.73 kg ha^{-1} (Table 1). The exchangeable Ca and Mg were 2.56 and 1.61(cmol [p+] kg^{-1}), available sulphur was 15.32 mg kg^{-1} and all the DTPA extractable micronutrients were above the critical limits (Fe-33.49, Mn-23.17, Cu-2.94 and Zn-1.38 mg kg^{-1}).

Initial soil physical, chemical and biological properties of the experimental site

Sl. No.	Physical properties of soil	
1.	Sand (%)	72.36
2.	Silt (%)	12.15
3.	Clay (%)	15.4
4.	Texture of soil	Sandy loam
5.	Bulk density (Mg m-3)	1.61
6.	MWHC (%)	23.52
	Chemical properties of soil	
7.	pH (1:2.5)	5.57
8.	EC (1:2) (dSm-1)	0.28
9.	Organic carbon (g kg-1)	4.19
10.	Available nitrogen (kg ha-1)	234.18
11.	Available P2O5 (kg ha-1)	35.16
12.	Available K2O (kg ha-1)	114.73
13.	Exchangeable calcium (cmol[p+] kg-1)	2.56
14.	Exchangeable magnesium (cmol[p+] kg-1)	1.61
15.	Available sulphur (mg kg-1)	15.32
16.	DTPA Fe (mg kg-1)	33.49
17.	DTPA Mn (mg kg-1)	23.17
18.	DTPA Zn (mg kg-1)	1.38
19.	DTPA Cu (mg kg-1)	2.94
	Biological properties	
20.	Dehydrogenase activity (µg TPF g-1 of soil day-1)	17.15
21.	Urease activity (µg NH+4 released g-1 soil hr-1)	199.43
22.	Phosphatase activity (µg PNP g-1 of soil hr-1)	9.85

Results and Discussion

Effect of different levels of fly ash on physical properties of acid soil under paddy cultivation

Results on the influence of fly ash on selected physical properties *viz.*, bulk density (BD), particle density (PD), porosity and maximum water holding capacity (MWHC) under paddy cultivation are presented in Table 2 and 3.

Bulk density and Particle density

The results of bulk density and particle density indicated that, the effect of fly ash and their combination with and without PGPR on bulk density showed a non-significant effect.

Porosity and MWHC

With regard to property of soil (Table 3) clearly showed that a higher value of porosity was observed in the treatments which received higher levels of fly ash. Among different treatments, significantly higher porosity was recorded in T_5 (59.41%) which found on par with T_9 (58.82%) and it was followed by T_3 (56.23%) and T_7 (55.67%). A significantly lower value of porosity was recorded in the control treatment (53.49%) where only RDF and FYM were added.

Table 2: Effect of different levels of fly ash on BD and PD of acid soil after harvest of the paddy

Treatment details	Bulk density	Particle density
	(Mg m^{-3})	
T_1: Control (RDF+ FYM)	1.52	2.55
T_2: T_1 + Fly ash 10 t ha^{-1}	1.49	2.52
T_3: T_1 + Fly ash 20 t ha^{-1}	1.48	2.49
T_4: T_1 + Fly ash 30 t ha^{-1}	1.46	2.48
T_5: T_1 + Fly ash 40 t ha^{-1}	1.45	2.47
T_6: T_1 + Fly ash 10 t ha^{-1} + PGPR	1.48	2.51
T_7: T_1 + Fly ash 20 t ha^{-1} + PGPR	1.48	2.50
T_8: T_1 + Fly ash 30 t ha^{-1} + PGPR	1.47	2.49
T_9: T_1 + Fly ash 40 t ha^{-1} + PGPR	1.46	2.47
T_{10}: T_1 + PGPR	1.51	2.53
S.Em±	0.03	0.04
C. D. at 5%	NS	NS

RDF: Recommended dose of fertilizer, **PGPR:** Plant growth promoting rhizobacteria, **FYM:** Farm yard manure

A higher dose of fly ash combined with and without PGPR significantly increased the water holding capacity of soil as compared to control treatment (RDF + FYM). Among different levels of fly ash, the treatment T_5 recorded significantly higher MWHC (35.05%) which found on par with T_9 with 34.70 per cent, T_4 with 34.31 per cent and followed by T_3 with 33.18 per cent. Significantly lower porosity value was recorded in the control treatment (T_1: 31.56%).

Application of fly ash with FYM improved permeability of soil as it is microsized particles with porous nature and heavily lower bulk density value thereby it is capable of reducing bulk density, and crust formation, improves the good structure and thereby the porosity and water holding capacity of soil increased noticeably. Similar findings were reported by Vimal and Nandita (2010) [33] and Asish and Sudhir (2012) [2].

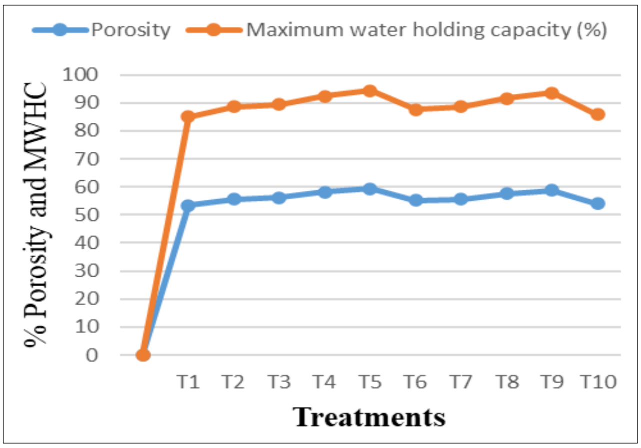

Fig 1: Effect of different levels of fly ash on porosity and MWHC of acid soil after harvest of the paddy

The increase in MWHC in fly ash amended soil was mainly due to the presence of Ca in fly ash that enhanced aggregation through the flocculation of soil particles, keeps the soil friable and that has increased water holding capacity of the soil. Application of fly ash either individually or in combination with FYM increased the water retention capacity of the soil mainly attributed to fly ash being microsized particles and porous nature can hold more amount of moisture and also reduced bulk density of soil. The calcium present in fly ash along with organic matter provides a congenial atmosphere to stabilize the physical environment. A similar finding also reported by Bhople *et al.* (2011) [4], Prem Kishor *et al*. (2009) [22], Samy *et al.* (2010) [25]. Asish and Sudhir (2012) [2] also obtained that 40 per cent level of fly ash application decreased bulk density, increased water holding capacity and soil porosity.

Table 3: Effect of different levels of fly ash on porosity and MWHC of acid soil after harvest of the paddy

Treatment details	Porosity (%)	Maximum water holding capacity (%)
T_1: Control (RDF+ FYM)	53.49	31.56
T_2: T_1 + Fly ash 10 t ha^{-1}	55.67	32.85
T_3: T_1 + Fly ash 20 t ha^{-1}	56.23	33.18
T_4: T_1 + Fly ash 30 t ha^{-1}	58.16	34.31
T_5: T_1 + Fly ash 40 t ha^{-1}	59.41	35.05
T_6: T_1 + Fly ash 10 t ha^{-1} + PGPR	55.11	32.52
T_7: T_1 + Fly ash 20 t ha^{-1} + PGPR	55.67	32.84
T_8: T_1 + Fly ash 30 t ha^{-1} + PGPR	57.58	33.97
T_9: T_1 + Fly ash 40 t ha^{-1} + PGPR	58.82	34.70
T_{10}: T_1 + PGPR	53.91	31.81
S.Em±	1.07	0.63
C. D. at 5%	3.15	1.86

RDF: Recommended dose of fertilizer, **PGPR:** Plant growth promoting rhizobacteria, **FYM:** Farm yard manure

Effect of different levels of fly ash on chemical properties of acid soil under paddy cultivation

Soil reaction (pH)

Application of higher levels of fly ash in combination with organic and inorganic fertilizer increased the pH of acid soil near to neutral over control treatment (T_1) from 30 DAT to 90 DAT. However the soil pH found non-significant at 30 DAT (Table 4).

At 60 and 90 DAT, the treatments which received higher levels of fly ash, FYM with and without PGPR increased the pH of acid soil over control treatment where no-fly ash was added. However, significantly higher soil pH of 5.95 and 6.38, respectively, were recorded in the treatment T_5 which found on par with T_9 with 5.94 and 6.37, respectively, T_4 with 5.93 and 6.36, respectively and followed by T_3 with 5.90 and 6.33, respectively. Significantly lower soil pH was recorded in the control treatment (T_1) with 5.80 and 5.98, respectively. Similar results were found at the harvest stage also.

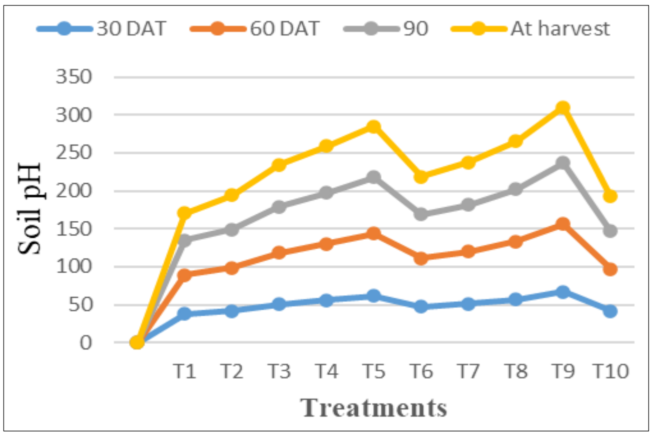

Fig 2: Effect of different levels of fly ash on pH of acid soil at different growth stages of paddy cultivation

In general, at all levels of fly ash with or without PGPR application, there was an increase in pH of acid soil as the days of growth 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) [32].

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) [16] and Chang *et al.* (2007) [9] 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.

Electrical conductivity (EC)

The addition of a different dose of fly ash did not influence the soil's electrical conductivity at all the stages.

Soil organic carbon

Combined application of fly ash with and without PGPR and FYM significantly increased the organic carbon content of acid soil as compared to control treatment. However, organic carbon content was found non-significant at 30 DAT (Table 4).

At 60 DAT, the application of a higher dose of fly ash with FYM and PGPR increased the soil organic carbon content over control treatment. Among different treatments, fly ash applied at 40 t ha^{-1} + FYM + Rec. RDF (T_5) recorded higher soil organic carbon content of 5.54 g kg^{-1} which remained statistically on par with T_9 which registered 5.53 g kg^{-1} and followed by T_3, T_7 with 5.21 and 5.20 g kg^{-1} respectively. Significantly lower soil organic carbon content was recorded in control (T_1) treatment with 4.60 g kg^{-1} where fly ash was not added and only RDF was applied. Similar results were followed in 90 DAT

There was an increase in the organic carbon content of the soil with an increase in the crop growth stage due to fly ash application along with FYM and PGPR. Significantly higher soil organic carbon content was recorded in T_5 and T_9 which received fly ash 40 t ha^{-1} with PGPR and FYM over control treatment. Even though the organic carbon content of fly ash is lower but a higher amount of soil organic carbon was observed in fly ash amended soil. This could be explained by the fact that the porous structure, high CEC and surface area of fly ash might have hold more carbon and thus increased soil organic carbon. Another main reason for increased organic carbon content in the soil might be due to contribution from FYM and their faster oxidation (decomposition) by PGPR and microorganisms. Similar results were also reported by Das *et al.* (2013) [10] and Sang *et al.* (2017) [26].

Available primary nutrients status in acid soil

Application of fly ash with and without PGPR showed that there was an increase in available N, P_2O_5 and K_2O status of acid soil up to 60 days after transplanting and thereafter there was a decline in available N, P_2O_5 and K_2O content in soil at 90 and harvest stage of the crop (Table 5).

Available nitrogen

A significantly higher available nitrogen status of acid soil was noticed in the treatments which received a combined application of higher levels of fly ash with PGPR over control treatment (T_1) where no-fly ash was applied (Table 5). There was a slight increase in available nitrogen content of soil and no significant effect was found due to the application of fly ash with PGPR when compared to the application of fly ash alone.

At 30 DAT, the maximum available nitrogen was recorded in the treatment T_9 (T_1 + Fly ash 40 t ha^{-1} + PGPR) with 296.17 kg ha^{-1} which found on par with T_5 (T_1 + Fly ash 40 t ha^{-1}) with 293.58 kg ha^{-1} and followed by T_7 (T_1 + Fly ash 20 t ha^{-1} + PGPR) which registered 267.27 kg ha^{-1}. Significantly lower available nitrogen was recorded in the treatment of T_1 (221.16 kg ha^{-1}).

Table 4: Effect of different levels of fly ash on electro chemical status of acid soil at different growth stages of paddy cultivation

Treatment details	Soil pH				Soil EC (dS m^{-1})				Soil OC (g kg^{-1})			
	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest
T_1: Control (RDF+ FYM)	5.74	5.80	5.86	5.98	0.28	0.29	0.31	0.32	4.31	4.60	5.10	5.61
T_2: T_1 + Fly ash 10 t ha^{-1}	5.79	5.85	6.27	6.59	0.28	0.30	0.32	0.32	4.33	4.82	5.30	5.83
T_3: T_1 + Fly ash 20 t ha^{-1}	5.84	5.90	6.33	6.65	0.29	0.31	0.33	0.33	4.37	5.21	5.73	6.30
T_4: T_1 + Fly ash 30 t ha^{-1}	5.87	5.93	6.36	6.69	0.30	0.33	0.34	0.35	4.38	5.47	6.02	6.62
T_5: T_1 + Fly ash 40 t ha^{-1}	5.89	5.95	6.38	6.71	0.31	0.34	0.36	0.36	4.41	5.54	6.09	6.70
T_6: T_1 + Fly ash 10 t ha^{-1} + PGPR	5.80	5.86	6.29	6.60	0.28	0.30	0.32	0.32	4.32	4.81	5.29	5.82
T_7: T_1 + Fly ash 20 t ha^{-1} + PGPR	5.82	5.88	6.31	6.63	0.29	0.31	0.33	0.33	4.35	5.20	5.72	6.29
T_8: T_1 + Fly ash 30 t ha^{-1} + PGPR	5.85	5.91	6.34	6.66	0.3	0.33	0.34	0.35	4.36	5.46	6.01	6.61
T_9: T_1 + Fly ash 40 t ha^{-1} + PGPR	5.88	5.94	6.37	6.70	0.31	0.34	0.36	0.36	4.37	5.53	6.08	6.69
T_{10}: T_1 + PGPR	5.74	5.80	6.22	6.54	0.28	0.30	0.32	0.32	4.32	4.80	5.28	5.81
S.Em±	0.05	0.015	0.013	0.01	0.012	0.017	0.02	0.014	0.04	0.027	0.029	0.038
C. D. at 5%	NS	0.04	0.04	0.03	NS	NS	NS	NS	NS	0.08	0.09	0.11

RDF: Recommended dose of fertilizer, PGPR: Plant growth promoting rhizobacteria, FYM: Farm yard manure.

At 60 DAT, among different treatments, the treatment T_9 (T_1+ Fly ash 40 t ha^{-1} + PGPR) recorded significantly higher available N status (328.73 kg ha^{-1}) which remained statistically on par with the treatments T_5, T_8 and T_4 (T_1 + Fly ash 40 t ha^{-1} + PGPR, T_1 + Fly ash 30 t ha^{-1}+ PGPR and T_1 + Fly ash 30 t ha^{-1}) which registered 325.87, 317.33 and 314.46 kg ha^{-1}, respectively, and followed by T_7 and T_3 treatment (296.66 and 293.79 kg ha^{-1}, respectively). Significantly lower available nitrogen content was obtained in the control treatment (245.49 kg ha^{-1}) where only FYM and RDF were added. Same trend was noticed in respect of available N status in soil at 90 DAT and at the harvest stage of the crop.

The higher status of available N was recorded due to integrated use of fly ash with PGPR and FYM which might be due to the effect of mineralization of nutrients by converting organic form of nutrients to inorganic form by soil micro-organisms and PGPR and thus increased the availability of nitrogen. A lower amount of available nitrogen was observed may be due to loss of nitrogen (Maiti 2003) [19]. After 60 DAT, there was a decline in available nitrogen content of soil at 90 DAT and harvest stage from initial available nitrogen because as paddy absorbed more nitrogen from soil at different growth stages thereby there was increase in yield of crop. The higher grain and straw yield of paddy due to maximum utilization of available N by the crop favoured by the effects of fly ash and FYM and PGPR on soil physical, chemical and biological properties. Improved status of soil available nitrogen by application of fly ash with organic and inorganic fertilizer was also reported by Das *et al.* (2013) [10], Rautaray *et al.* (2003) [23].

Available phosphorus

The data presented in Table 5 revealed that there was a significant increase in the available phosphorus status of acid soil in the treatments where a higher level of fly ash was applied along with PGPR and FYM as compared to control treatment. Fly ash application along with PGPR slightly increased the available phosphorus content of acid soil and no significant effect was found at all growth stages of paddy as compared to the application of fly ash alone.

A significant variation in available P_2O_5 status of acid soil was observed due to different treatments. At 30 DAT, a significantly higher available phosphorus status was noticed in T_9 (Fly ash 40 t ha^{-1} + PGPR + Rec. RDF and FYM) which registered 66.90 kg ha^{-1} which found on par with T_5 treatment (T_1 + Fly ash 40 t ha^{-1}) with 61.48 kg ha^{-1} and followed by T_8 (T_1 + Fly ash 30 t ha^{-1}+ PGPR) with 57.13 kg ha^{-1} which remained statistically on par with T_4 (T_1 + Fly ash @ 30 t ha^{-1}) with 55.75 kg ha^{-1}. Significantly lower available phosphorus content was observed in T_1 treatment (38.15 kg ha^{-1}) which received only RDF and FYM. Similar results were recorded in 60, 90 DAT and at the harvest stage.

The treatments which received higher levels of fly ash along with FYM and PGPR significantly increased the available phosphorus content in acid soil as compared to other treatments. The possible mechanism for increased P_2O_5 availability in acid soil might be due to increased soil pH upon fly ash addition. Fly ash application modifies the soil pH by the release of alkaline compounds present in fly ash, which neutralized the soil acidity and thus increased the soil pH. This indicates that the neutralizing effect of the alkali fly ash on acidic soil is a very important factor for increased P_2O_5 availability. Fly ash is an ameliorator of P complexing metals (Al^{3+}, Fe^{3+}), promoter of microbial activity and hastening phosphorus mineralization. Thus it increased the available P_2O_5 content in acid soil with fly ash addition (Lee *et al.*, 2008).

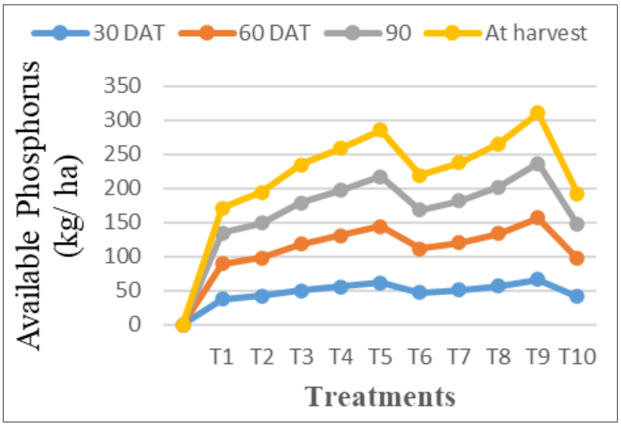

Fig 3: Effect of different levels of fly ash on available phosphorus at different growth stages of paddy cultivation

Under anaerobic conditions (rice cultivation) ferric iron is reduced to ferrous iron and the mobility of phosphorus and Fe increased by decreasing the Fe-P fixation in acid soil (Chang *et al.* 2007) [9]. The favourable effect of fly ash on P availability was also reported by Matte and Kene (1995) [20].
Another possible mechanism for increasing available phosphorus content in acid soil might be due to the application of fly ash along with PGPR which enhanced the availability of P_2O_5 by mineralizing organic phosphorus in soil and by solubilizing the precipitated phosphate such as Fe-P (Yong *et al.* 2007). The phosphorus solubilizing bacteria (PSB) helped in realising more phosphorus from native as well as applied P and also protecting the fixation of added phosphate and render phosphorus more available for the plants leading to increased phosphorus content. Similar findings were reported by Chang *et al.* (2007) [9] and Gaind and Gaur (2002) [13]. In addition, the high Si content of fly ash might have influenced in increasing available phosphorus concentration in the soil during rice cultivation. Silicate ions enhanced the solubility of phosphorus in soil by displacing P from ligand exchange sites (Duarah *et al.*, 2011) [12] and by inhibiting phosphorus ion sorption for the same specific anion exchange site.

Available potassium

The effect of fly ash with and without PGPR on K_2O availability in acid soil is presented in Table 6. At 30 DAT, the maximum available potassium was recorded in the treatment T_9 with 307.32 kg ha^{-1} which found on par with the value of 299.44 kg ha^{-1} of T_5 treatment and followed by T_7 which registered 267.92 kg ha^{-1} and T_3 (256.1 kg ha^{-1}). Significantly lower available potassium content was recorded in the treatment of T_1 (182.57 kg ha^{-1}). There was a slight increase in available potassium content and no significant effect was found due to the application of fly ash with PGPR when compared to the application of fly ash alone. Same trend was followed in 60, 90 DAT and at the harvest stage.

Table 5: Effect of different levels of fly ash on primary nutrients status of acid soil at different growth stages of paddy cultivation

Treatment details	Available Nitrogen (kg ha^{-1})				Available P_2O_5 (kg ha^{-1})				Available K_2O (kg ha^{-1})			
	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest
T_1: Control (RDF+ FYM)	221.16	245.49	225.58	196.39	38.15	51.12	45.78	35.78	182.57	273.19	248.60	157.01
T_2: T_1 + Fly ash 10 t ha^{-1}	243.30	270.06	248.17	216.05	42.16	56.49	50.59	45.20	246.25	369.38	336.13	211.77
T_3: T_1 + Fly ash 20 t ha^{-1}	264.68	293.79	269.97	235.04	50.59	67.79	60.71	55.59	256.10	384.15	349.57	220.24
T_4: T_1 + Fly ash 30 t ha^{-1}	283.30	314.46	288.97	251.57	55.75	74.71	66.90	61.26	279.74	419.61	381.84	240.57
T_5: T_1 + Fly ash 40 t ha^{-1}	293.58	325.87	299.45	260.70	61.48	82.38	73.77	67.55	299.44	449.16	408.73	257.51
T_6: T_1 + Fly ash 10 t ha^{-1} + PGPR	245.89	272.93	250.80	218.35	47.61	63.80	57.13	50.40	250.19	375.29	341.50	215.16
T_7: T_1 + Fly ash 20 t ha^{-1} + PGPR	267.27	296.66	272.61	237.33	51.21	68.65	61.48	56.29	267.92	401.88	365.71	230.41
T_8: T_1 + Fly ash 30 t ha^{-1} + PGPR	285.89	317.33	291.60	253.87	57.13	76.56	68.56	62.78	287.62	431.43	392.60	247.35
T_9: T_1 + Fly ash 40 t ha^{-1} + PGPR	296.17	328.74	302.09	263.00	66.90	89.65	80.28	73.51	307.32	460.98	419.49	264.29
T_{10}: T_1 + PGPR	234.15	259.91	238.83	207.93	41.53	55.65	49.84	45.63	189.12	283.55	258.03	162.64
S.Em±	4.35	5.02	4.72	4.56	2.03	2.37	2.52	1.94	7.79	10.03	10.15	6.09
C. D. at 5%	13.41	14.57	14.09	13.83	5.91	7.35	7.28	6.03	22.58	31.08	28.43	18.09

RDF: Recommended dose of fertilizer, PGPR: Plant growth promoting rhizobacteria, FYM: Farm yard manure

Fly ash amended soil with and without PGPR had significantly increased available potassium status in acid soil which might be due to the higher concentration of K_2O found in fly ash as compared to other nutrients and improvement of physical and chemical characteristics of the soil which helped in the increased availability of potassium in the soil. Another possible reason for increasing K_2O in soil might be due to PGPR application along with fly ash. *Bacillus mucilogenosus* which has strong potassium dissolving ability and thus increased the potassium content in soil (Das *et al.*, (2013) [10].
After 60 DAT, there was a decline in the availability of potassium in the soil might be due to the maximum utilization of nutrients by crop due to its increased availability in soil in the fly ash amended treatments. Increased K availability by fly ash application has also been reported by Bhoyer (1998) [5], Sharma and Kalra (2006) [28, 29]. Deshmukh *et al.*, 2000 [11] reported that fly ash application might improve the K, Ca, Mg and S status of acid soil.

Secondary nutrients status in soil

The results obtained about the effect of higher levels of fly ash with and without PGPR on exchangeable Ca and Mg and available sulphur status of acid soil at different growth stages of paddy are presented in Table 6.

Exchangeable Ca

It was noticed from the results presented in Table 6 that, application of higher levels of fly ash with and without PGPR significantly increased the exchangeable Ca content of acid soil at all the plant growth stages over control treatment (T_1) where only RDF and FYM were added. Fly ash application along with PGPR slightly increased the exchangeable Ca content of acid soil at all growth stages of paddy as compared to the application of fly ash alone.
At 30 DAT, a significant increased exchangeable Ca content of soil was noticed in T_9 (Fly ash @ 40 t ha^{-1} + PGPR + Rec. RDF and FYM) which noticed 4.23 cmol (p^+) kg^{-1} which

found on par with T_5 treatment (Fly ash @ 40 t ha^{-1} + Rec. RDF and FYM) which registered 4.11 cmol (p^+) kg^{-1} and followed by T_7 (T_1 + Fly ash @ 20 t ha^{-1} + PGPR) with 3.17 cmol (p^+) kg^{-1} and T_3 (2.88 cmol (p^+) kg^{-1}). Significantly lower exchangeable Ca content was observed in T_1 treatment (3.10 cmol (p^+) kg^{-1}) where only FYM and RDF were added.

At 60 and 90 DAT, among different treatments, T_9 (Fly ash 40 t ha^{-1} + PGPR + Rec. RDF and FYM) recorded significantly higher exchangeable calcium (4.69 and 5.28 cmol (p^+) kg^{-1}, respectively) content which remains statistically on par with T_5 (Fly ash 40 t ha^{-1} + 100% RDF and FYM) with 4.61 and 5.06 cmol (p^+) kg^{-1}, respectively and followed by T_7 (Fly ash 20 t ha^{-1} + PGPR + Rec. RDF and FYM) which registered 3.17 and 3.90 cmol (p^+) kg^{-1}, respectively as compared to all other treatments. Significantly lower exchangeable Ca content was observed in T_1 treatment (2.64 and 2.83 cmol (p^+) kg^{-1}, respectively). Same trend was seen in harvest stage also.

Exchangeable Mg

Data recorded at 30 DAT revealed that treatment T_9, showed significantly higher exchangeable Mg content in soil which received T_1 + Fly ash 40 t ha^{-1} + PGPR with 3.27 cmol (p^+) kg^{-1}which remained statistically on par with T_5 treatment which registered 3.15 cmol (p^+) kg^{-1} and followed by T_7 with 2.14 cmol (p^+) kg^{-1}. Significantly lower exchangeable Mg content was observed in T_1 treatment (1.62 cmol (p^+) kg^{-1}). Application of fly ash has slightly increased the exchangeable Mg status of acid soil but its effectiveness was less as compared to fly ash application with PGPR.

The higher value of exchangeable Mg content in acid soil was recorded by the treatment T_9 (Fly ash 40 t ha^{-1} + PGPR + Rec. RDF and FYM) with 3.73 cmol (p^+) kg^{-1} which was on par with T_5 (T_1+ Fly ash 40 t ha^{-1}) which recorded 3.65 cmol (p^+) kg^{-1} and followed by T_7 (T_1 + Fly ash 20 t ha^{-1}+ PGPR) with 2.21 cmol (p^+) kg^{-1}. Lower exchangeable Mg (1.68 (p^+) kg^{-1}) was noticed in control at 60 DAT. A similar trend was observed even at 90 DAT and at the harvest stage.

Application of fly ash at higher doses increased the exchangeable calcium and magnesium content of acid soil which might be due to the higher concentration of Ca and Mg in the fly ash which rapidly released in to the soil solution and thereby it increased the exchangeable bases of soil. Fly ash amended soil is not only increased soil pH but also improved the chemical properties of acidic soils and CEC which helped to increase the content of Ca and Mg. Such observations were also noticed by Lehmann *et al*. (2003) [17] and Chan *et al.* (2008) [8]. Deshmukh *et al.*, 2000 [11] reported that fly ash application may improve the K, Ca, Mg and S status of deficient soil.

Available sulphur

Treatments that received higher levels of fly ash with and without PGPR showed maximum available sulphur as compared to non-fly ash treatment at different growth stages of paddy. The significantly higher available sulphur content of acid soil was noticed in the treatments which received a combined application of fly ash with PGPR over control treatment (T_1) where no-fly ash was applied (Table 6).

As per data represented at 30 and 60 DAT, treatment T_9 (Fly ash 40 t ha^{-1} + PGPR + 100% RDF and FYM) showed the maximum value of available sulphur (15.76 and 13.18 mg kg^{-1}, respectively) which remain statistically on par with the treatment T_5 (T_1 + Fly ash 40 t ha^{-1}) with 15.45 and 12.82 mg kg^{-1}, respectively and followed by T_7 (Fly ash 20 t ha^{-1} + PGPR + 100% RDF and FYM) with 11.88 and 9.90 mg kg^{-1}, respectively, which were highly superior over other treatments. Significantly lower available sulphur of 9.66 and 8.45 kg ha^{-1}, respectively was noticed in T_1 treatment. Same trend was recorded in 90 and harvest stage.

Table 6: Effect of different levels of fly ash on secondary nutrient status of acid soil at different growth stages of paddy cultivation

Treatment details	Exch. Ca (c mol (p+) kg^{-1})				Exch. Mg (c mol (p+) kg^{-1})				Available S (mg kg^{-1})			
	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest
T_1: Control (RDF+ FYM)	2.58	2.64	2.83	2.94	1.62	1.68	1.87	1.98	9.66	8.45	8.29	7.29
T_2: T_1 + Fly ash 10 t ha^{-1}	2.84	2.73	2.90	3.12	1.88	1.77	1.94	2.16	10.63	8.89	8.53	7.53
T_3: T_1 + Fly ash 20 t ha^{-1}	3.10	3.18	3.72	3.80	1.92	2.14	2.36	2.76	11.59	9.66	9.90	8.90
T_4: T_1 + Fly ash 30 t ha^{-1}	3.87	3.95	4.10	5.81	2.91	2.29	3.14	4.85	14.49	12.07	10.14	9.14
T_5: T_1 + Fly ash 40 t ha^{-1}	4.11	4.61	5.06	6.60	3.15	3.65	4.10	5.65	15.45	12.82	11.27	10.27
T_6: T_1 + Fly ash 10 t ha^{-1} + PGPR	2.88	2.88	3.21	3.22	2.21	1.92	2.25	2.25	10.77	8.98	8.98	7.98
T_7: T_1 + Fly ash 20 t ha^{-1} + PGPR	3.17	3.20	3.90	3.95	2.14	2.21	2.76	2.94	11.88	9.90	9.66	8.66
T_8: T_1 + Fly ash 30 t ha^{-1} + PGPR	3.91	3.39	4.46	5.92	2.95	2.43	3.50	4.96	14.63	12.20	10.59	9.59
T_9: T_1 + Fly ash 40 t ha^{-1} + PGPR	4.23	4.69	5.28	6.85	3.27	3.73	4.32	5.84	15.76	13.18	11.51	10.51
T_{10}: T_1 + PGPR	2.71	2.76	2.80	2.84	1.75	1.80	1.84	1.88	10.14	8.82	8.45	7.45
S.Em±	0.04	0.03	0.07	0.08	0.05	0.04	0.03	0.06	0.11	0.12	0.09	0.08
C. D. at 5%	0.13	0.09	0.23	0.27	0.15	0.13	0.1	0.21	0.33	0.37	0.26	0.25

RDF: Recommended dose of fertilizer, PGPR: Plant growth promoting rhizobacteria, FYM: Farm yard manure

Sulphur content in soil varied significantly with the application of different doses of fly ash under paddy cultivation. This might be due to the contribution of available sulphur to the soil after the mineralization of fly ash which was influenced by PGPR and FYM. Reddy *et al.* (2010) and Deshmukh *et al.*, 2000 [11] reported that fly ash application might improve the Ca, Mg and S status of deficient soil. It can be seen from the data (Table 7) that available sulphur was decreased from 3o DAT to 90 DAT under paddy cultivation might be due to, under the submerged condition the available sulphur (SO_4^{2-}) undergo reduction process and is reduced to hydrogen sulphide (H_2S) and further converted into insoluble iron sulphide (FeS). Such observations were also noticed by Lehmann *et al*. (2003) [17] and Chan *et al.* (2008) [8].

DTPA extractable micronutrients status in soil

The data pertaining to the DTPA extractable micronutrients like iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) status in the soil at different growth stages of paddy as influenced by fly ash are presented in Table 7. Significantly higher available micronutrient status of acid soil was noticed in the treatments which received a combined application of higher levels of fly ash with PGPR over control (T_1) which received only RDF and FYM. There was an increase in available Fe and Mn content of soil but a decrease in Zn and Cu content in acid soil with an increased in the crop growth period due to fly ash application.

Available Fe

Application of fly ash with and without PGPR significantly increased the available Fe content of acid soil from 30 DAT to harvest stage of the crop over control and there was a slight increased in available Fe content and no significant effect was found due to the application of fly ash with PGPR when compared to the application of fly ash alone.

It can be seen from Table 7 that, the data of DTPA extractable Fe was significantly influenced by the application of fly ash with and without PGPR. At 30 and 60 DAT, significantly higher DTPA extractable Fe content of 41.30 mg kg^{-1} and 46.40 mg kg^{-1}, respectively was recorded in the treatment T_9 (T_1 + Fly ash 40 t ha^{-1} + PGPR) which was on par with T_5 treatment (T_1 + Fly ash 40 t ha^{-1}) with 40.77 mg kg^{-1} and 45.81 mg kg^{-1}, respectively and followed by T_7 (T_1 + Fly ash 20 t ha^{-1} + PGPR) with 38.15 mg kg^{-1} and 42.86 mg kg^{-1}, respectively and significantly lower DTPA extractable Fe content was recorded in T_1 treatment with 34.95 mg kg^{-1} and 39.27 mg kg^{-1}, respectively. A similar trend was followed with respect to DTPA extractable Fe content at 90 DAT and harvest stage of the crop.

Table 7: Effect of different levels of fly ash on DTPA extractable micronutrients status of acid soil at different growth stages under paddy cultivation

Treatment details	Fe (mg kg^{-1})				Mn (mg kg^{-1})				Cu (mg kg^{-1})				Zn (mg kg^{-1})			
	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest
T_1: Control (RDF+ FYM)	34.95	39.27	41.91	44.12	23.65	25.13	26.31	29.56	2.63	2.28	1.96	1.75	0.91	0.73	0.67	0.6
T_2: T_1 + Fly ash 10 t ha^{-1}	35.74	40.16	42.86	45.12	24.18	25.70	26.91	30.23	2.64	2.29	1.97	1.76	1.04	0.83	0.77	0.69
T_3: T_1 + Fly ash 20 t ha^{-1}	37.59	42.24	45.09	47.46	25.44	27.03	28.30	31.80	2.67	2.31	1.99	1.78	1.10	0.88	0.81	0.73
T_4: T_1 + Fly ash 30 t ha^{-1}	39.47	44.35	47.34	49.83	26.71	28.38	29.71	33.39	2.72	2.35	2.03	1.81	1.18	0.94	0.87	0.78
T_5: T_1 + Fly ash 40 t ha^{-1}	40.77	45.81	48.90	51.47	27.59	29.31	30.69	34.48	2.79	2.42	2.08	1.86	1.24	0.99	0.91	0.82
T_6: T_1 + Fly ash 10 t ha^{-1} + PGPR	37.08	41.66	44.47	46.81	25.09	26.66	27.91	31.36	2.66	2.30	1.98	1.77	1.06	0.85	0.78	0.7
T_7: T_1 + Fly ash 20 t ha^{-1} + PGPR	38.15	42.86	45.75	48.16	25.81	27.43	28.72	32.27	2.69	2.33	2.00	1.79	1.12	0.90	0.82	0.74
T_8: T_1 + Fly ash 30 t ha^{-1} + PGPR	39.70	44.61	47.61	50.12	26.86	28.54	29.89	33.58	2.76	2.39	2.06	1.84	1.19	0.96	0.88	0.79
T_9: T_1 + Fly ash 40 t ha^{-1} + PGPR	41.30	46.40	49.53	52.14	27.95	29.69	31.09	34.93	2.84	2.46	2.12	1.89	1.25	1.00	0.92	0.83
T_{10}: T_1 + PGPR	35.30	39.66	42.33	44.56	23.88	25.38	26.57	29.86	2.64	2.29	1.97	1.76	0.97	0.77	0.71	0.64
S.Em±	0.63	0.71	0.76	0.81	0.44	0.45	0.47	0.53	0.04	0.04	0.03	0.03	0.03	0.02	0.03	0.02
C. D. at 5%	1.86	2.09	2.24	2.39	1.31	1.34	1.39	1.56	0.13	0.13	0.1	0.09	0.09	0.07	0.08	0.06

RDF: Recommended dose of fertilizer, PGPR: Plant growth promoting rhizobacteria, FYM: Farm yard manure DAT: Days after transplanting

Available Mn

At 30 and 60 DAT, significantly higher DTPA extractable Mn status in soil (27.95 mg kg^{-1} and 29.69 mg kg^{-1}, respectively) was recorded in the treatment T_9 which remained statistically on par with T_5 with 27.59 mg kg^{-1} and 29.31 mg kg^{-1}, respectively and followed by T_7 with 25.81 mg kg^{-1} and 27.43 mg kg^{-1}, respectively and significantly lower value of 23.65 mg kg^{-1} and 25.13 mg kg^{-1}, respectively was recorded in T_1 treatment.

Among different treatments, at 90 and harvest stage of the crop, T_9 recorded higher DTPA extractable Mn content of 31.09 mg kg^{-1} and 34.93 mg kg^{-1}, respectively (Fly ash 40 t ha^{-1} + PGPR + 100% RDF and FYM) which remained statistically on par with T_5 (Fly ash 40 t ha^{-1} + 100% RDF and FYM) with 30.69 mg kg^{-1} and 34.48 mg kg^{-1}, respectively and followed by T_7 (Fly ash 20 t ha^{-1} + PGPR + 100% RDF and FYM) with 28.72 mg kg^{-1} and 32.27 mg kg^{-1}, respectively. Lower Mn content was noticed in control with 26.31 mg kg^{-1} and 29.56 mg kg^{-1}, respectively.

Application of increased levels of fly ash combined with PGPR increased DTPA extractable Fe and Mn content in acid soil. This might be attributed to fly ash application neutralized the soil acidity by the release of alkaline compounds from fly ash and thus increased the soil pH. This increased soil pH reduces the P fixation with Fe and thus reduced Fe-P increased the availability of Fe formation. Application of fly ash along with PGPR increased Fe content in acid soil by the dissolution of iron oxide coatings with organic acids produced by P solubilizers causing a reduction in Fe-P and thus increases the availability of Fe content in the soil. These results are corroborate with the findings of Sheela (2006) [30].

Another possible reason for increased Fe and Mn content in acid soil might be due to, under paddy cultivation, ferric iron (Fe^{3+}) is reduced to ferrous iron (Fe^{2+}) and Mn^{4+} to Mn^{2+} and thereby mobility and solubility of Fe and Mn increased in soil under rice cultivation. The findings of Sikka and Kansal (1995) [31], Rautaray *et al*. (2003) [23], Chang *et al.* (2007) [9] and Selvakumari *et al.* (2000) [27] also supports the results of increasing Fe and Mn status of the experiment.

An increase in DTPA extractable micronutrient status in soil treated with fly ash and FYM might also be due to enhanced mineralization and solubilization of native minerals. The findings of Yeledhalli *et al.* (2008) [35] also support the results of increasing the micronutrient status of the experiment.

Available Cu

The available zinc content of acid soil as influenced by different treatments is presented in Table 7. Higher levels of fly ash with and without PGPR decreased the Cu content.

At 30 and 60 DAT, significantly higher DTPA extractable Cu status 2.84 mg kg^{-1} and 2.46 mg kg^{-1}, respectively was recorded in the treatment T_9 which received T_1 + Fly ash 40 t ha^{-1} + PGPR which found on par with T_5 (Fly ash 40 t ha^{-1} + 100% RDF and FYM) with 2.79 mg kg^{-1} and 2.42 mg kg^{-1}, respectively and followed by T_7 (T_1 + Fly ash 20 t ha^{-1} + PGPR) with 2.69 mg kg^{-1} and 2.33 mg kg^{-1}, respectively and significantly lower value of 2.63 mg kg^{-1} and 2.28 mg kg^{-1}, respectively of Cu was recorded in T_1 treatment. A similar trend was followed with respect to DTPA extractable Cu content at 90 DAT and harvest stage of the crop

Available Zn

At 30 and 60 DAT, significantly higher DTPA extractable Zn content in acid soil was recorded in the treatment T_9 with 1.25 mg kg^{-1} and 1.00 mg kg^{-1}, respectively which found on par with the treatment T_5 with 1.24 mg kg^{-1} and 0.99 mg kg^{-1}, respectively and followed by T_7 with 1.12 mg $kg^{-1}$and 0.90 mg kg^{-1}, respectively and significantly lower value of 0.91 mg kg^{-1} and 0.73 mg kg^{-1}, respectively was recorded in T_1 treatment. A similar trend was followed with respect to DTPA extractable Zn content at 90 DAT and harvest stage of the crop.

The availability of the micronutrients in acid soil increased with increasing doses of fly ash with its integration along with organic and inorganic fertilizer over control. This might be due to fact that fly ash and FYM are the important sources of micronutrients, hence soil micronutrients status were increased.

The increase in available nutrient status of acid soil due to fly ash application might be attributed to two reasons; firstly, the direct addition of nutrients to the soil through fly ash and FYM, secondly, due to favourable soil conditions associated with the application of fly ash and FYM. Similar results were reported by Rani and Kalpana, (2010), Rautaray *et al*. (2003) [23] and Selvakumari *et al.* (2000) [27]. An increase in Fe, Mn, Cu and Zn status in soil due to application of fly ash @15 t ha^{-1} was also reported by Deshmukh *et al.* (2000) [11]. The PGPR enrich the soil with major plant nutrients such as nitrogen (N) by fixing it from the atmosphere, phosphorous (P) and potassium (K) by solubilizing them from the soil.

Conclusion

Fly ash is alkaline in nature which is not only used as a supplemental source of plant nutrients but also an amendment for improving acid soil. From the field investigation it is noticed that, the application of fly ash along with PGPR, FYM and RDF resulted in favourable physical and chemical properties of acid soil as compared to the application of fly ash alone and control (RDF + FYM).

Lower soil BD (1.45 Mg m^{-3}), high maximum water holding capacity (35.05%) and soil porosity (59.41%) was recorded in the treatment T_5 (Fly ash 40 t ha^{-1}). Significantly higher available nitrogen (328.74 kg ha^{-1}), P (89.65 kg ha^{-1}), K (460.98 kg ha^{-1}), Ca (6.85 c mol (p+) kg^{-1}), Mg (5.84 c mol (p+) kg^{-1}) and available sulphur content (15.76 mg kg^{-1}) in acid soil were recorded in T_9 treatment (T_1 + Fly ash 40 t ha^{-1} + PGPR). Highest soil available Fe, Zn, Cu and Mn were recorded in the treatment T_9 (T_1 + fly ash 40 t ha^{-1}along with PGPR) which was on par with $T_5$and followed by T_7 treatment (T_1 + Fly ash 20 t ha^{-1} + PGPR). Application of fly ash @ 40 t ha^{-1} with PGPR, FYM and recommended dose of fertilizer to rice crop under acid soil was found to be the best treatment for improving the properties of acid soil.

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