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ORIGINAL RESEARCH

Soil fertility and nutrient uptake of rice influenced by plant growth promoting microbes, seaweed extract and humic acid fortified in situ rice residue compost

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Abstract

Purpose Intensive rice cultivation, non-addition of organic matter and indiscriminate use of inorganic fertilizers lead to soil fertility deterioration; on other side, farmers are burning huge quantities of rice residue causing severe air pollution warrants pragmatic disposal solution. *In situ* composting is considered as a potential alternative to destruction of crop residues. Moreover, fortification of crop residue with beneficial microbes and bio stimulants increase the availability of nutrients which constitutes an integral component in sustainable agriculture. The objective was to evaluate the effect of *in situ* rice residue compost fortification with PGPM consortia, humic acid and seaweed extract on the soil nutrient availability and uptake by rice.

Method The experiment was conducted in a RBD at field condition. Rice was grown under 10 treatments comprising a control (100 % NPK) and nine treatments (*in situ* rice residue, fortified FYM, fortified *in situ* rice residue along with 100, 75 and 50 % NPK).

Results *In situ* rice residue fortified with PGPM consortia, humic acid and seaweed extract significantly improved the soil carbon, nutrients' availability (macro and micro) and soil fertility. Combined application of fortified rice residue compost with 75% NPK resulted in significantly higher rice yields (grain 6.03 t ha^{-1} and straw 8.57 t ha^{-1}) and nutrient uptake.

Conclusion *In situ* rice residue composting provides promising straw disposal method as well as recoups lost share of organic matter and nutrients to soil. Farmers may adapt *in situ* compost to restore soil health without causing environmental hazard and also sustain crop productivity.

Keywords *In situ* rice residue compost, PGPM consortia, Humic acid, Seaweed extract, Fortification, Nutrient availability and uptake

Introduction

Rice is the most cultivated cereal crop worldwide and is pronounced to be the target food to the lives of billions of people around the world (Nguyen and Ferrero 2006). India is the second largest producer of rice. Rice production has been 112.91 mt during the year 2017-18 (DAC and FW 2019). After the green revolution, India became self-sufficient in the production of food grains. However, to meet the growing demand of food grains for the burgeoning population, extensive cropping has been practiced which affected the soil health. Soil fertility levels are adversely affected due to the continuous cultivation of high yielding crops. Maintenance of soil fertility and productivity is the dire need of present day farming as the level of soil organic matter is getting depleted due to over use of inorganic fertilizers (Goyal et al. 2006). To renew the soil productivity, recycling of crop biomass and application of compost to the field is a viable alternative (Gaind and Nain 2011). Soil organic matter deterioration causes a severe threat to sustainability; there is an absolute need to replenish by returning crop residue. Total amount of crop residue in India is estimated at 350 x 10^6 kg per year, of which rice resi-

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due constitutes about 51 per cent (Lal and Kimble 2002). Huge quantities of rice straw are left for disposal after harvest of the crop (Jusoh et al. 2013). Every year, more than 100 mt of paddy straw is produced in India (Veena and Pandey 2011). There is also opinion among the farmers that the paddy straws left after machine harvesting are less preferred by the farm animals. In northern India, surplus paddy straw residues generally to a large extent are burnt in open field. The burning of paddy straw in the field leads to greenhouse gases (GHG) emissions cause severe air pollution. The GHG emissions contribution through open-field burning of rice straw in India, Thailand and Philippines are estimated to be 0.05, 0.18, and 0.56 per cent, respectively (Gadde et al. 2009). Rice residue exemplifies one among the promising organic waste product whose huge quantity warrants pragmatic disposal solution. On the other hand, paddy straw composting is a suitable alternative to manage this resource, besides its use for restoration of soil health (Gaind et al. 2009). Straw is the sole organic material available in significant quantities to most rice farmers. About 40 percent of the nitrogen (N), 30 to 35 per cent of the phosphorus (P), 80 to 85 per cent of the potassium (K), and 40 - 50 per cent of the sulphur (S) taken up by rice crop remains in vegetative plant parts at crop maturity (Dobermann and Fairhurst 2002). Straw supplements various macro and micro nutrients, which contribute to the nutrient budgeting of farms, if added to soil (Lal 2013). Incorporation of rice residue after harvest did not reduce the yield of succeeding crop and soil pH greatly influenced the addition of crop residue management (Gaind and Nain 2011). Application of rice straw at 5 t ha^{-1} could save the potassium chloride fertilizers equal to 100 kg ha^{-1} (Barus 2012). The rice straw compost is found to improve the crop yield as well as soil properties (Gaind and Nain 2010; Aminah et al. 2019). The crop residue treatments positively influenced some of the soil parameters over control (Surekha et al. 2003). Nitrogen uptake by grain and straw significantly increased by rice residue and nutrient management practices (Verma and Pandey 2013). Many studies had revealed the use of rice straw or residue compost which can improve soil nutrients and health. However, the major disadvantage associated with the incorporation of rice residue is immobilization of N due to the wider C:N ratio, which results in N deficiency (Mandal et al. 2004). To overcome the ill effects of the N immobilization, inoculation of rice residue with potential microbial paves a way for faster decomposition process. Recent researches have reported that the rice straw amended with microbial inoculants hastens the composting process bringing C:N ratio down to 15:1 within 60 days (Sharma et al. 2014), which enhances the soil macro and micro nutrients availability compared to compost without effective microorganisms (Jusoh et al. 2013; Vijayaprabhakar et al. 2017). Bio fertilizers improve the yield of crops by 25 per cent and reduce the requirement of inorganic fertilizers to 20-50 per cent (Simarmata 2013; Ghany et al. 2013). Further, the application of bio-augmented straw compost combined with bio fertilizers consortia has a greater prospect to remediate soil health and increases productivity in a sustainable way (Simarmata et al. 2015). Fortification of compost with single or consortia of beneficial microorganisms like N-fixers, P-solubilizers or K-mobilizers and biocontrol agents further enriches compost to produce bio-organic products (Singh et al. 2019). Bio-stimulants such as humic acid, seaweed extract whose application to plants or soil facilitates the nutrients uptake by the plant and increases their tolerance to stress or improves their agronomic performance (Du Jardin 2015). *In situ* composting of rice residue is considered as most financially viable and the workable option to the farmers. Hence, in the regime of injudicious and indiscriminate use of synthetic molecules for higher productivity which causes irreparable damages to nature, the relevance of conserving natural resources including soil, water and beneficial microbes is gaining momentum. *In situ* rice residue composting is considered as a potential alternative to the destruction of rice residues which might contribute to pollution. Moreover, fortifying the crop residues with microbial consortia and bio stimulants has innate potential to solubilize and increases the availability of the otherwise unavailable nutrients constitutes an integral component in the sustainable evergreen revolution. The present study is more comprehensive and unique in nature which aimed to determine the effect of combined application of rice crop recommended PGPM consortia (bio fertilizers and bio control agents) and bio stimulants *viz.,* humic acid and seaweed extract as fortified *in situ* rice residues for better and efficient utilization of rice residues in the restoration of soil fertility, yield and uptake of nutrients by rice.

Materials and methods

Study location and site properties

The study was conducted at ICAR-Perunthalaivar Kamaraj Krishi Vigyan Kendra (PKKVK), Kurumbapet, Puducherry, India (11.9407 °N latitude and 79.7661 °E longitude) during the Kharif season (July – November 2019). The soil properties of the experiment site were; pH 6.9, EC 0.21 dS m^{-1}, Available soil nutrient status showed low organic Carbon (0.23%) and alkaline $KMnO_4$-N (156 kg ha^{-1}), high Olsen-P_2O_5 (41 kg ha^{-1}), medium NH_4OAc-K_2O (147 kg ha^{-1}), medium DTPA-Zn (1.78 mg kg^{-1}) and Cu (0.49 mg kg^{-1}), high Fe (11.51 mg kg^{-1}) and Mn (14.80 mg kg^{-1}).

Treatments imposed

The following ten treatments were imposed; T_1 - 100% recommended dose of NPK, T_2 - 100% NPK+ *in situ* rice residue (straw & stubble) compost (IRRC), T_3 - 100% NPK+ Plant Growth Promoting Microbial (PGPM) consortia, Humic acid (HA) and Seaweed extract (SWE) fortified FYM (FFYM) 5 t ha^{-1}, T_4 - 100% NPK+ *in situ* rice residue compost fortified with PGPM, HA and SWE (FIRRC), T_5 - 75% NPK+ IRRC, T_6 - 75% NPK+ FFYM 5 t ha^{-1}, T_7 - 75% NPK+ FIRRC, T_8 - 50% NPK+ IRRC, T_9 - 50% NPK+ FFYM 5 t ha^{-1}, and T_{10} - 50% NPK+ FIRRC.

The Individual Plant Growth Promoting Microbial (PGPM) lignite based cultures *viz., Azospirillum lipoferum,* Phosphobacteria *(Bacillus megaterium)*, potash solubilizing bacteria (*Frateuria aurantia*), zinc solubilizing bacteria (*Bacillus subtilis*) with 2x10^8 cfu/g of living cells were obtained from the Department of Microbiology, Faculty of Agriculture, Annamalai University. The bio-control agents *Pseudomonas fluorescence* with 2x10^8cfu/g and *Trichoderma sp.* with 2x10^7cfu/g living cells were obtained from the Bio control laboratory, ICAR-PKKVK, Puducherry. PGPM cultures were mixed in equal quantities to make consortia and used for fortification purpose. Fortification of crop residue with bio fertilizers and bio control agents can also help to add desired microbial communities with specific functions, enhance nutrient use efficiency of the soils and ensure proper availability of nutrients for longer time durations (Singh et al. 2019). Humic Acid prepared from lignite following the fractionation procedure of Stevenson (1994) and a commercial formulation of seaweed extract (*Sargassum wightii)* from ARVEE Biotech, Chidambaram were also used for fortification of the compost.

Preparation of PGPM consortia, Humic acid and Seaweed extract fortified FYM (FFYM)

The calculated quantities of FYM were taken and PGPM consortia at the rate of 2.8 kg t^{-1}, humic acid and sea weed extract each 100 ml t^{-1} were sprinkled over FYM and mixed well. Water was sprinkled to maintain 60 per cent water holding capacity level. The enriched composting was carried out externally for 20 days under shade using the standard protocol prescribed by Tamil Nadu Agricultural University, Coimbatore, India (Kavitha and Subramanian 2007). At weekly intervals, the material was stirred and 60 per cent moisture was maintained by determining the moisture of compost in hot air oven. The FFYM was applied to the respective treatment plots at the rate of 5 t ha^{-1} before transplanting.

In situ of rice residue compost with and without PGPM, HA and SWE fortification

The random assessment study made in farmer's holdings indicated that around 7.5 t ha^{-1} of rice residue (straw and stubble) was realized from every rice crop. On this basis, *in situ* incorporation of rice residues (IRRC) were carried out, 20 days before transplanting at the rate of 7.5 t ha^{-1} in the respective treatment plots to ensure desirable decomposition and N deficiency due to immobilization. Earlier, Yadvinder et al. (2005) and Gupta et al. (2007) also successfully demonstrated the rice residue incorporation 20 days before transplanting of rice crop.

For *in situ* fortification (FIRRC) treatments, respective plots (20 m^2 area) were applied with rice residues at the rate of 7.5 t ha^{-1}. PGPM consortia at 14 kg ha^{-1}, humic acid and sea weed extract at the rate of 500 ml ha^{-1} were sprinkled uniformly over rice residues and incorporated into the soil. Irrigations at regular intervals were done to maintain adequate moisture for the decomposition of rice residues. After 20 days, the transplanting of rice seedlings was carried out. The nutrient contents of rice residue and FYM are presented in Table 1.

Experimental details

The field experiment was conducted in Randomized Block Design with three replications using rice variety ADT (R) 53 of 110 days' duration. The inorganic fertilizers were applied to respective plots following the recommended fertilizer schedule of 120:40:40 NPK kg ha^{-1}. Fifty per cent N as urea, 100 per cent P as super phosphate and 50 per cent K as muriate of potash were applied as basal and the remaining 50 per cent N and K were applied in two splits at tillering and panicle initiation stages.

Table 1 Nutrient content of Rice residue and FYM

Organic manure	pH	EC (dS m^{-1})	OC (%)	N (%)	P (%)	K (%)	Zn (mg kg^{-1})	Fe (mg kg^{-1})
Rice residue	7.2	3.47	33.6	0.46	0.21	1.02	36.4	123
FYM	7.1	2.11	18.2	0.52	0.27	0.51	77.2	181

Soil parameters *viz*., pH, EC, organic carbon, soil available N, P, K, Zn, Cu, Fe and Mn were analyzed in soil samples at active tillering, panicle emergence and post-harvest stages. The major and micro nutrients' content of plant samples at critical stages and in grain and straw at harvest were estimated by adopting di acid extract ($HClO_4$: H_2SO_4 4: 1 ratio) as per the procedure of Jackson (1973) and uptake were calculated. The yield parameters of rice were also recorded.

Statistical analysis

The data on soil and plant nutrient content as well as yield parameters were subjected to ANOVA (Analysis of Variance) in accordance with the experimental design (Randomized Block Design) using WASP 2.0 statistical package and CD (Critical Difference) values were calculated at 0.05 P-level (Gomez and Gomez 1984).

Results and discussion

Effect on soil pH and EC

The application of fortified organic manures with PGPM, HA and SWE have marginally lowered the soil pH at tillering stage and pH increased marginally during panicle emergence and post-harvest soil, but failed to significantly differ among the treatments (Table 2). The soil EC (dS m^{-1}) failed to significantly differ among the treatments at tillering, panicle emergence and post-harvest stages. The EC values recorded at tillering stage ranged from 0.21 to 0.33 dS m^{-1}, at panicle emergence stage ranged from 0.21 to 0.29 dS m^{-1} and post-harvest soils ranged from 0.20 to 0.25 dS m^{-1}. The decline in pH could be due to the production of organic acids during the decomposition of rice residue and FYM. Similar findings were ascribed by Guled et al. (2002), Dhar et al. (2014), and Harikesh et al. (2017). Soil EC did not

Table 2 Effect of PGPM consortia, HA and SWE fortified *in situ* Rice residue compost on soil pH and EC

Treatments	Soil pH			EC (dS m^{-1})		
	AT	PE	PH	AT	PE	PH
T_1- Control (100 % NPK)	6.75	7.04	7.15	0.24	0.21	0.20
T_2 - 100 % NPK+ IRRC	6.39	6.84	6.94	0.26	0.24	0.23
T_3 - 100 % NPK+ FFYM	6.52	7.00	7.13	0.33	0.29	0.23
T_4 - 100 % NPK+ FIRRC	6.46	6.86	7.15	0.31	0.27	0.23
T_5 - 75 % NPK+ IRRC	6.38	6.81	6.91	0.24	0.24	0.23
T_6 - 75 % NPK+ FFYM	6.61	6.91	7.01	0.28	0.24	0.24
T_7 - 75 % NPK+ FIRRC	6.57	6.85	6.97	0.28	0.27	0.25
T_8 - 50 % NPK+ IRRC	6.56	6.76	6.90	0.21	0.21	0.21
T_9 - 50 % NPK+ FFYM	6.50	6.87	7.21	0.23	0.24	0.22
T_{10} - 50 % NPK+ FIRRC	6.47	6.85	6.94	0.23	0.23	0.22
S.Ed	NS	NS	NS	NS	NS	NS
C.D(p=0.05)	NS	NS	NS	NS	NS	NS

AT- Active Tillering, PE- Panicle Emergence and PH- Post Harvest soils change significantly which could be due to the inherent high buffering capacity of soil which resists change as a result of the addition of organic manures and fertilizers. The results of the study also corroborate the findings of Kumar et al. (2008), Goyal et al. (2009) and Dhar et al. (2014).

Organic carbon (%)

Soil organic carbon (SOC) is a key parameter for evaluating soil health. The organic carbon status of soil was found to be superior with incorporation of *in situ* rice residue or FYM compost fortified with PGPM consortia, HA and SWE (Fig. 1). Among the treatments, PGPM consortia, HA and SWE fortified *in situ* rice residue compost application along with 100% NPK (T_4), 75% NPK (T_7) and 100 % NPK + fortified FYM (T_3) recorded significantly superior and comparable SOC content of 0.50, 0.46 and 0.45 %, respectively at tillering stage. The lowest SOC content of 0.24 % was observed in treatment with only chemical fertilizers applied plots (T_1-100% NPK) at tillering stage. SOC content in panicle emergence stage was greatly influenced by the addition of PGPM consortia, HA and SWE fortified *in situ* rice residue compost application along with 100% NPK (T_4) and 75% NPK (T_7) by recording a comparable SOC of 0.45 and 0.41%, respectively. The least carbon percentage was found in the soil of plot which received chemical fertilizers alone (T_1- 0.22%). The results of the soil samples taken after harvest showed that T_7 -75% NPK+ FIRRC application recorded the highest SOC of 0.35 % which was statistically on par with $T_4>T_2>T_8>T_{10}>T_5$. The lowest SOC of 0.19 % was recorded in T_1 - 100% NPK. The addition of rice residue or FYM sustains the SOC content compared to non-addition which could be due to the decomposition of FYM or rice residue resulting in the enhancement of organic carbon content of the soil. Among the organic manures, rice residue incorporation recorded the higher SOC content compared to FYM application at post-harvest soils, which might be due to higher carbon content in rice residue in the building of soil microbial population. Moreover, inoculation of rice residue with PGPM would have facilitated the performance of added as well as native microbes and thus higher SOC was observed. Similar results were reported by Regar et al. (2005), Singh et al. (2009), Surekha et al. (2003) and Simarmata et al. (2016).

Available nutrient status of soil

The available macro nutrients *viz.,* $KMnO_4$-N, Olsen-P and NH_4OAc- K and micro nutrients namely DTPA - zinc, copper, iron and manganese analyzed in soil samples taken at critical stages of crop growth and at harvest revealed that the application of PGPM consortia, HA and SWE fortified organic manure (either FYM / rice residue compost) significantly influenced the soil available macro and micro nutrients content at different growth stages over unfortified rice residue compost.

Alkaline KMnO4-N. At tillering stage, T_3 - 100 % NPK + FFYM at 5 t ha^{-1} recorded a significantly higher alkaline $KMnO_4$-N content of 201.6 N kg ha^{-1} compared to the other treatments (Fig. 2). However, it was statistically on par with treatments: T_4 (194.13 N kg ha^{-1}), T_6 (190.4 N kg ha^{-1}) and T_7 (186.7 N kg ha^{-1}). The lowest alkaline $KMnO_4$-N was recorded in treatment T_8 (149.3 N kg ha^{-1}). During panicle emergence and post-harvest stages, the maximum N content of 194.13 and 186.67 N kg ha^{-1} was recorded in T_7 -75% NPK+ FIRRC. The lowest alkaline $KMnO_4$-N availability of 141.87 N kg ha^{-1} at panicle emergence and 130.67 N kg ha^{-1} at harvest stages were recorded in T_8- 50 % NPK with unfortified rice residue. At later stages, FIRRC applied soils recorded higher available N compared to FFYM application, which might be due to the slow and steady release of nitrogen from rice residues. Rice residue amended with microbial inoculants hasten the composting process and bring C: N ratio down (Sharma et al. 2014). The soil available N increased due to addition of organic materials and microbial decomposition led to the conversion of organically bound nitrogen into inorganic form. Moreover, nitrogen fixation bacteria in PGPM played a significant role in atmospheric nitrogen fixation. The enhanced rate of N mineralization noticed in fortified rice residue incorporated soil than unfortified residue, might be due to the fact that the added PGPM have enhanced decomposition rates of rice residue. Similar results were reaffirmed with the findings of Prasad and Sinha (2000), Surekha et al. (2004) and Goyal et al. (2009).

Olsen-P. Similar to alkaline $KMnO_4$-N content, the phosphorus availability also increased by the addition of FIRRC and FFYM compost at different stages (Fig. 3). In tillering stage, the maximum Olsen - P content was recorded in T_3 - 100% NPK+ FFYM at 5 t ha^{-1} and T_4 -100% NPK+ FIRRC with values of 61.53 and 60.8 P_2O_5 kg ha^{-1}, respectively. During panicle emergence stage, T_7 -75% NPK along with FIRRC application was found superior in Olsen - P content (47.54 P_2O_5 kg ha^{-1}) and T_6 - 75% NPK + FFYM at 5 t ha^{-1} (47.29 P_2O_5 kg ha^{-1}). In post-harvest soil samples, the highest Olsen - P content was recorded in T_7 (44.43 P_2O_5 kg $ha^{-1)}$, which was closely followed by T_6 (41.78 P_2O_5 kg ha^{-1}), T_4 (40.99 P_2O_5 kg $ha^{-1)}$ and T_3 (40.24 P_2O_5 kg $ha^{-1)}$. The increased availability of phosphorus noticed in FIRRC and FFYM compost might be due to the production of organic acids by PGPM microbes during the process of decomposition, which helped in the mineralization of native as well as applied phosphorus (Tolanur and Badanur 2003). Further, acid or alkaline phosphate enzyme plays a pivotal role in mineralization of organic P, the enzymatic activity has been enhanced due to PGPM and bio stimulants addition in rice residues (Sharma et al. 2014). The findings were in the agreement with other studies, Savithri and Hameed (1994), Dhull et al. (2004), Gupta et al. (2007) and Vijayaprabhakar et al. (2017) who averred the same results.

NH_4OAc- K. Addition of *in situ* rice residue significantly influenced the NH_4OAc- K content at all stages. The potassium availability was maximum at early stages and minimum at post-harvest soils (Fig. 4). Among the treatments, FIRRC + 100 % NPK (T_4) was found superior in increasing the potassium content (214.33 kg ha^{-1}) at tillering and NPK at 75 % by recording a NH_4OAc-K content of 189 and 161.67 ha^{-1}, respectively at panicle emergence and post-harvest stage. The lowest soil potassium status was recorded in T_1 - 100% NPK 155 (AT), 132.33 (PE) and 126.33 kg ha^{-1} (harvest stage) where rice residue or FYM were not added. The potash solubilizing bacteria in PGPM consortia plays a vital role in the production of organic acids which led to potassium mineralization as evidenced by Gogoi et al. (2018). The organic matter reduces K fixation; added organic matter interacted with potassium clay to release from non-exchangeable fixation to the available pool. The higher NH_4OAc- K availability in rice residue applied plots might also be due to the fact that rice straw contains 80 to 85 % of total K uptake of rice crop (Dobermann and Fairhurst 2002) and thus, rice residue incorporation had resulted in higher soil K. Similar results were also reported by Yadvinder et al. (2004), Yaduvanshi and Sharma (2007), Kumar et al. (2008) and (Vijayaprabhakar et al. 2017).

DTPA - Zn, Cu, Fe and Mn. The micronutrients' contents of soil were significantly enhanced by the addition of PGPM, humic acid and sea weed extract fortified organic manure. The highest DTPA-Zn, Cu, Fe and Mn contents were recorded at tillering and the least content was noticed at post-harvest soils (Fig. 5-8). In tillering stage, highest DTPA extractable Zn (2.49 mg kg^{-1}), Cu (0.83 mg kg^{-1}), Fe (16.15 mg kg^{-1}) and Mn (23.26 mg kg^{-1}) were recorded in fortified FYM at 100% NPK (T_3). During the panicle emergence stage, the highest content of Zn - 2.22 mg kg^{-1} and Fe -14.15 mg kg^{-1} was recorded by T_7, whereas highest Cu-0.61 mg kg^{-1} and Mn-16.69 mg kg^{-1} were recorded by T_6 and T_3, respectively. At harvest stage, the highest micronutrient availability viz., Zn, Cu, Fe and Mn were observed in T_7 with the content of 2.13, 0.56, 13.25 and 14.17 mg kg^{-1}, respectively. The lowest availability of micronutrients was recorded in T_1 at all the stages of crop growth. At harvest, control recorded a DTPA extractable micronutrient content of Zn (1.48 mg kg^{-1}), Cu (0.39 mg kg^{-1}), Fe (9.43 mg kg^{-1}) and Mn (11.13 mg kg^{-1}). Non incorporation of either rice residue or FYM led to the depletion of soil available micronutrients, whereas this organic matter addition resulted in building up of soil micronutrients, as a result of organic acids' production during decomposition, which chelated the micronutrients and thereby increased content was recorded. The findings were similar to earlier results of Singaravel et al. (2005) and Kumar and Singh (2010). The integrated application of organic manures and inorganic fertilizers resulted in higher soil micronutrients availability as reported by Vijayaprabhakar et al. (2017). Composting of rice residue with microorganisms resulted in augmenting the micro nutrients compared to compost without microorganisms (Jusoh et al. 2013).

Nutrient content and uptake

The nutrient content of rice was analyzed at tillering, panicle emergence stages as well as in grain and straw and the results were presented in Tables 3 to 6. A significantly higher N content of 1.51, 1.37 and 0.66 at active tillering, grain and straw, respectively was recorded in the treatment T_3 - 100% NPK+ FFYM at 5 t ha^{-1}. During panicle emergence stage, the highest N content was recorded with T_4 - 100% NPK+ FIRRC (1.23 %). The least N content was recorded by the treatment T_8 at active tillering (1.11 %), panicle emergence (0.80 %), grain (1.18 %) and straw (0.38 %). The uptake of N was significantly influenced by the various fortified manures. The treatment T_3 - 100% NPK+ FFYM at 5 t ha^{-1} recorded significantly highest N uptake of 67.57,

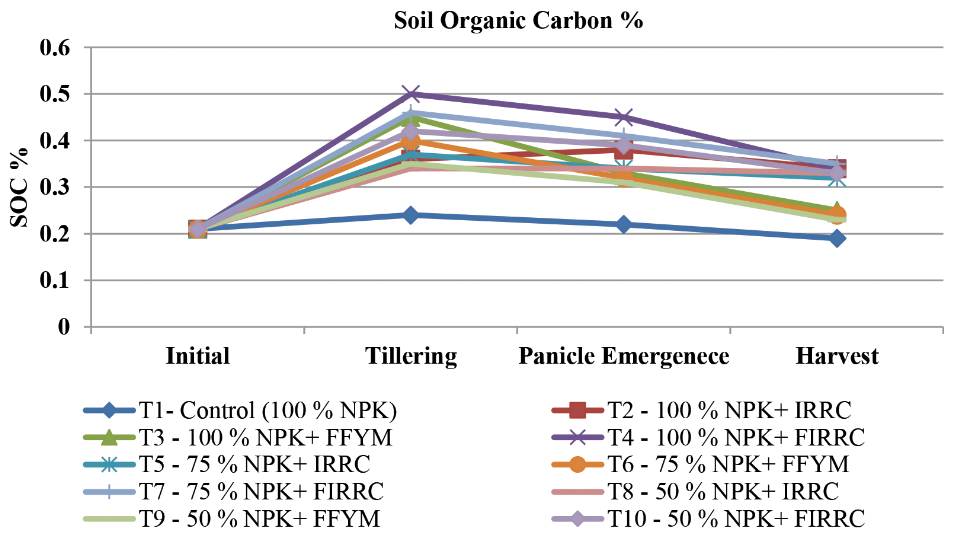

Fig. 1 Effect of PGPM, HA and SWE fortified organic manures on soil organic carbon (%)

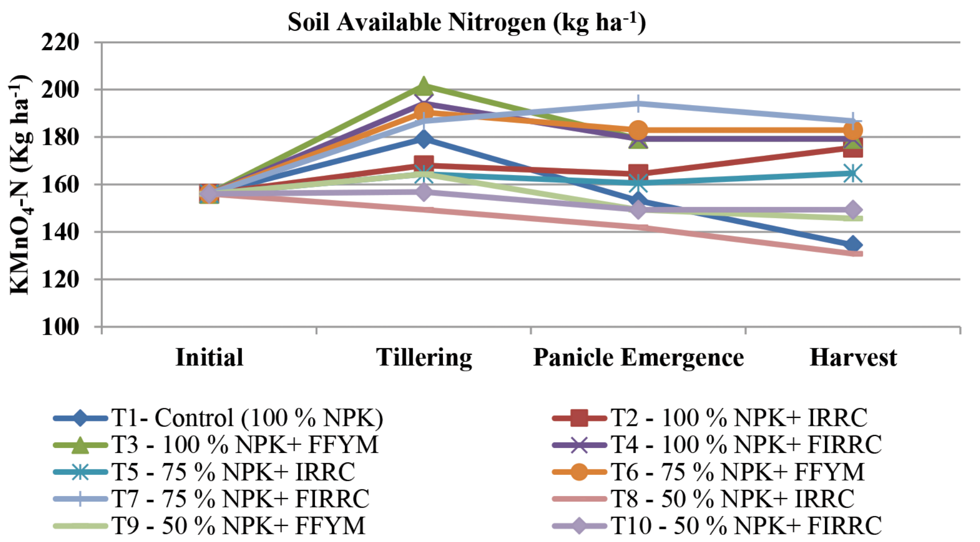

Fig. 2 Effect of PGPM, HA and SWE fortified organic manures on soil available nitrogen (kg ha^{-1})

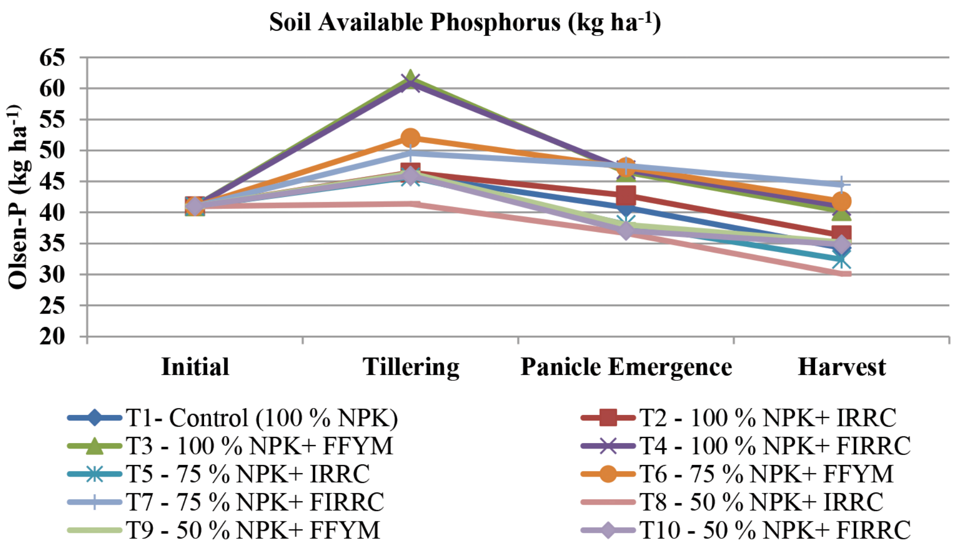

Fig. 3 Effect of PGPM, HA and SWE fortified organic manures on soil available phosphorus (kg ha^{-1})

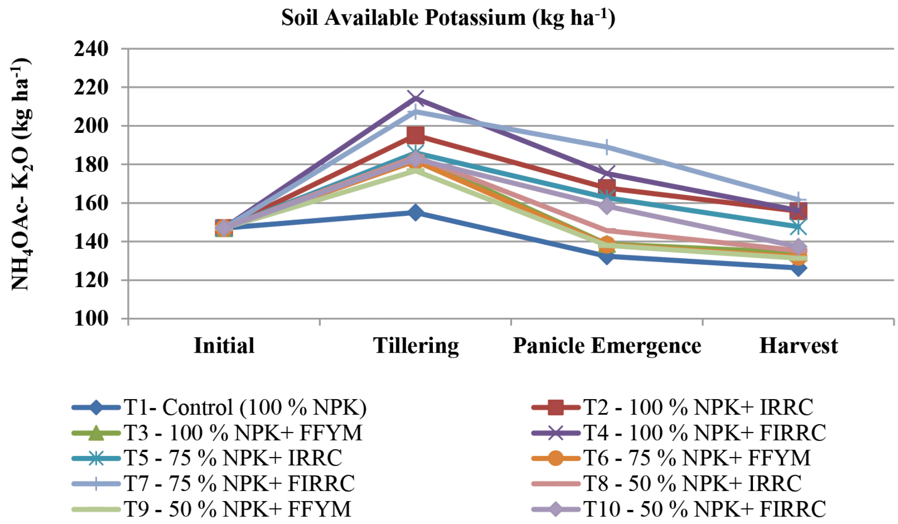

Fig. 4 Effect of PGPM, HA and SWE fortified organic manures on soil available potassium (kg ha^{-1})

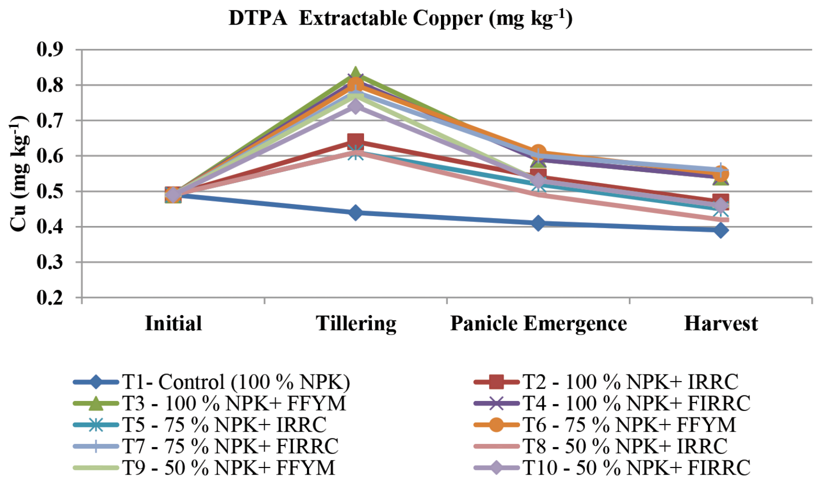

Fig. 5 Effect of PGPM, HA and SWE fortified organic manures on soil available copper (mg kg^{-1})

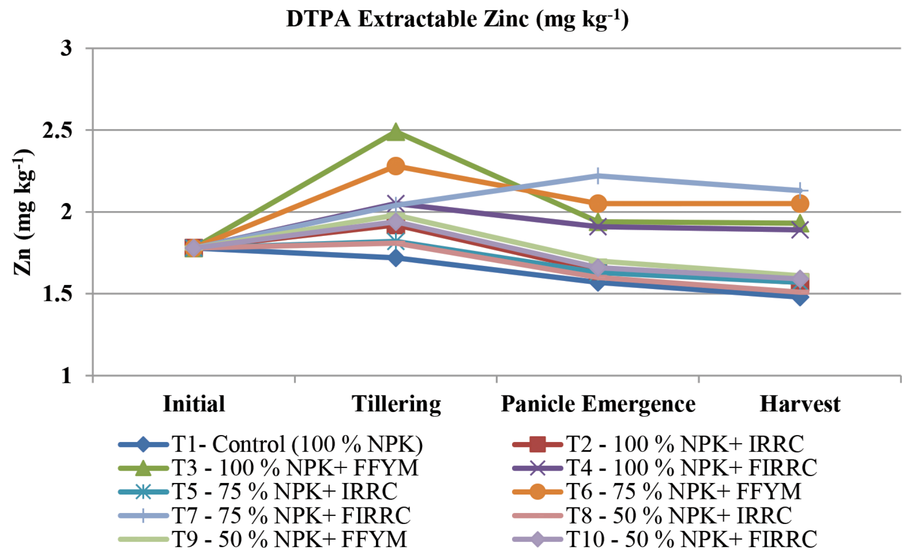

Fig. 6 Effect of PGPM, HA and SWE fortified organic manures on soil available zinc (mg kg^{-1})

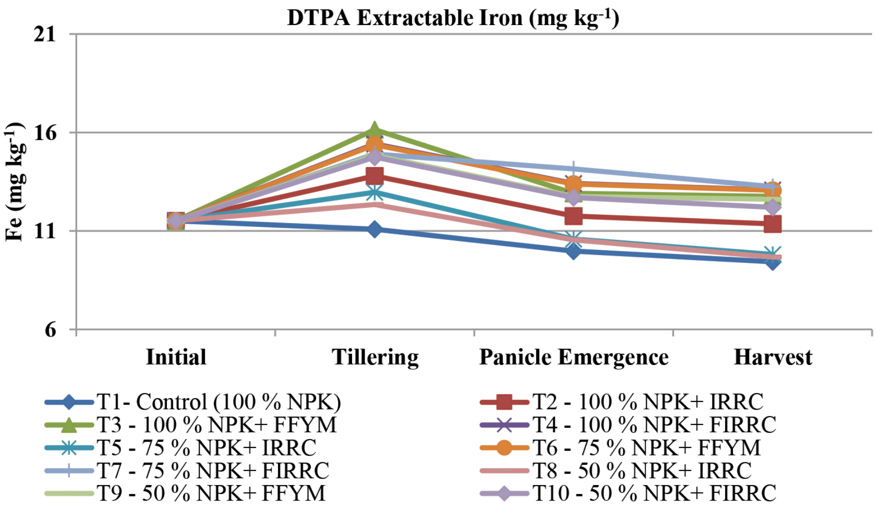

Fig. 7 Effect of PGPM, HA and SWE fortified organic manures on soil available Iron (mg kg^{-1})

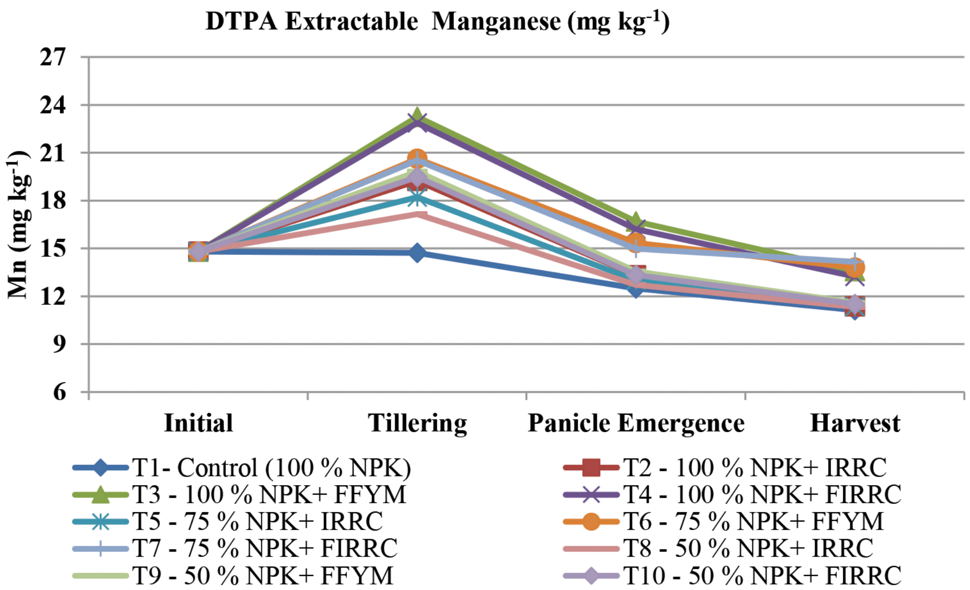

Fig. 8 Effect of PGPM, HA and SWE fortified organic manures on soil available manganese (mg kg^{-1})

129.94 and 55.41 kg ha^{-1} in active tillering, panicle emergence and in straw at harvest, respectively, whereas T_7 recorded the maximum N uptake in grain (80.67 kg ha^{-1}). The lowest N uptake of 32.60, 59.51, 47.02 and 20.59 kg ha^{-1} at tillering, panicle emergence, grain and straw respectively were recorded in T_8- a half dose of NPK+ IRRC without fortification (Table 4). The highest N fertilization at 100 % inorganic fertilizers along with fortified compost influenced higher N content and uptake by rice crop when compared to low N level of fertilization at 75 % and 50%. This might be due to higher N availability immediately after application of inorganic fertilizers, mineralization of organic manure and biological N fixation by PGPM, humic acid and sea weed extract which led to increase the availability of N in soil resulting in better root establishment, favouring greater absorption and utilization of nitrogen. Similar findings were also reported by Das et al. (2001) and Verma and Pandey (2013).

The phosphorus content at tillering stage ranged from 0.30 to 0.46 per cent in various treatments. The highest P content in rice was recorded in treatment T_3 where FFYM + 100% NPK were applied and the lowest P content was recorded in unfortified *in situ* rice compost plus inorganic fertilizers at the rate of 50 % NPK. At panicle emergence stage, the treatments T_7, T_3, T_4

and T_6 recorded statistically comparable P content of 0.32, 0.31, 0.31 and 0.30 %, respectively. The grain and straw P concentration were significantly influenced by organic residues fortification. Among the treatments, the highest P content was recorded by the treatment T_7 which recorded content of 0.32 and 0.20 per cent in grain and straw, respectively. At all the stages, the lowest P concentration was recorded in the treatment T_8. The T_7 -75% NPK along with FIRRC application was found to have statistically superior P uptake in panicle emergence (34.10 kg ha^{-1}), grain (19.04 kg ha^{-1}) and straw (16.82 kg ha^{-1}) and lowest p uptake was recorded in T_8 with values of 8.72, 15.39, 9.14 and 6.39 kg ha^{-1} in tillering, panicle emergence, grain and straw content, respectively. The higher P content was noticed at the initial stage in plots applied with FFYM compost, whereas plots with fortified in rice residue compost recorded higher P content at later stages, which might be due to the differential nutrient release pattern of FYM and rice residue. The higher P content and uptake of P in grain and straw in treatment with enriched organic manure might be due to the production of organic acids by microbes and enzyme activities during the process of composting resulting in decreased pH of material being composted and increased release of fixed P (Rashid et al. 2004). Organics enriched with inorganic P are subjected to biological mineralization resulting in production of phosphor humus complexes, which easily supply nutrients to plants. (Basavaraj and Manjunathaiah 2003; Ditta et al. 2015).

A profound influence of rice residue compost on potassium content of rice was significantly influenced at tillering, panicle emergence, grain and straw samples. Highest K content was observed with T_4 (1.84 %) at tillering, T_7 (1.48 %) in panicle emergence, T_7 (0.51 %) in grain and T_4 (1.56 %) in straw. The lowest K content was noticed in control (T_1) with values of 1.33, 1.21, 0.29 and 1.32 % in active tillering, panicle emergence, grain and straw, respectively. The addition of FIRRC or FFYM had appreciably increased the K uptake of rice at all stages. Among the treatments, the highest uptake of 78.48, 157.92, 30.52 and 133.04 kg ha^{-1} potassium were recorded in T_4 at tillering and in T_7 at panicle emergence, grain and straw, respectively. The lowest K uptake was noticed in T_8. The K content and uptake were significantly higher at 100% inorganic fertilizers combined with organic manures' application. This might be due to higher nutrient availability immediately after the application of inorganic fertilizers. Whereas at later stages namely panicle emergence and harvest stages, 75 % of inorganic fertilizers with organic manures application favoured for a greater K availability in soil. Further, the application of seaweed extracts could have enhanced the effectiveness of fertilizers as well as nutrient utilization from soil (Frankenberger and Arshad 1995; Rathore et al. 2009) and thus resulted in the higher nutrient concentration and uptake by rice. The findings are parallel to the view of Layek et al. (2017).

Micronutrients' content and uptake were significantly influenced by the addition of PGPM consortia, HA and SWE fortified organic manures (Table 5 and 6). At tillering stage, among the treatments T_3 - 100% NPK+ FFYM at 5 t ha^{-1} recorded highest micronutrients content of Zn – 44.04 mg kg^{-1} , Cu-15.59 mg kg^{-1}, Fe - 284.42 mg kg^{-1} and Mn-132.68 mg kg^{-1} and uptake of Zn – 196.47 g ha^{-1}, Cu-69.52 g ha^{-1}, Fe – 1271.61 g ha^{-1} and Mn-591.09 g ha^{-1}. The lowest content was obtained in T_1 - 34.32 Zn mg kg^{-1}, 12.66 Cu mg kg^{-1}, 241.24 Fe mg kg^{-1} and 100.05 Mn mg kg^{-1}. The lowest uptake was recorded in T_8 - 101.17 Zn g ha^{-1}, Cu-37.14 g ha^{-1}, Fe -753.18 g ha^{-1} and Mn-314.26 g ha^{-1}. Whereas the treatment T_7- FIRRC plus 75 % NPK recorded highest micronutrients' content and uptake at panicle emergence, in grain and straw. During panicle emergence stage, content of Zn - 37.04, Cu -13.79 , Fe - 230.47 and Mn-96.89 mg kg^{-1} and uptake of Zn - 395.27, Cu - 147.19, Fe-2496.28 (with T_6 - %75 NPK + FFYM) and Mn-1035.10 g ha^{-1} were recorded. In grain, content of Zn-29.40, Cu -5.85, Fe-102.19 and Mn-47.19 mg kg^{-1} and uptake of Zn - 177.15, Cu -35.29, Fe-616.03 and Mn - 284.71 g ha^{-1} were recorded. In straw, content of Zn-41.58, Cu - 8.81 , Fe - 178.31 and Mn - 109.52 mg kg^{-1} and uptake of Zn - 356.10, Cu -75.42, Fe-1528.02 and Mn-939.48 g ha^{-1} were recorded. The lowest content was recorded in control (T_1), where there is no addition of organic manures and lowest uptake was observed in T_8.

Highest micronutrients' content and uptake observed in FFYM + 100 % NPK inorganic fertilizers at tillering stage might be due to the combined application of well decomposed FFYM and inorganic fertilizers which could have increased the proportion of labile carbon and nitrogen directly by stimulating the activity of the microorganisms. The PGPM, HA and SWE increases solubility of micronutrients and thus favoured greater micro nutrients' content and uptake by rice. Further, the synergistic effect between nitrogen and micronutrients enhances micronutrients' content and availability. The findings were similar to studies of Duhan and Singh (2002); Chaudhary

Table 3 Effect of PGPM consortia, HA and SWE fortified *in situ* Rice residue compost on the N, P and K content of rice

Treatments	Nitrogen (%)				Phosphorus (%)				Potassium (%)			
	AT	**PE**	**G**	**S**	**AT**	**PE**	**G**	**S**	**AT**	**PE**	**G**	**S**
T_1 - Control (100 % NPK)	1.35	1.15	1.22	0.54	0.37	0.24	0.27	0.14	1.33	1.21	0.29	1.12
T_2 - 100 % NPK+ IRRC	1.29	1.03	1.31	0.51	0.36	0.23	0.28	0.15	1.73	1.37	0.44	1.30
T_3 - 100 % NPK+ FFYM	1.51	1.22	1.37	0.66	0.46	0.31	0.28	0.17	1.75	1.40	0.45	1.32
T_4 - 100 % NPK+ FIRRC	1.48	1.23	1.35	0.55	0.44	0.31	0.29	0.18	1.84	1.45	0.50	1.36
T_5 - 75 % NPK+ IRRC	1.24	0.94	1.23	0.51	0.30	0.23	0.27	0.14	1.62	1.35	0.42	1.29
T_6 - 75 % NPK+ FFYM	1.48	1.19	1.32	0.62	0.43	0.30	0.29	0.19	1.58	1.33	0.35	1.22
T_7 - 75 % NPK+ FIRRC	1.45	1.18	1.34	0.60	0.43	0.32	0.32	0.20	1.79	1.48	0.51	1.35
T_8 - 50 % NPK+ IRRC	1.11	0.80	1.18	0.38	0.30	0.21	0.23	0.12	1.61	1.33	0.37	1.28
T_9 - 50 % NPK+ FFYM	1.22	0.93	1.21	0.50	0.34	0.22	0.26	0.13	1.51	1.32	0.34	1.21
T_{10} - 50 % NPK+ FIRRC	1.14	0.84	1.20	0.45	0.32	0.21	0.26	0.13	1.76	1.38	0.48	1.34
S.Ed	0.04	0.05	0.06	0.04	0.05	0.06	0.06	0.06	0.07	0.07	0.06	0.07
C.D(p=0.05)	0.091	0.112	0.084	0.066	0.06	0.045	0.045	0.046	0.129	0.116	0.065	0.072

AT- Active Tillering, PE- Panicle Emergence, G- Grain and S- Straw

Table 4 Effect of PGPM consortia, HA and SWE fortified *in situ* Rice residue compost on N, P and K uptake of rice

Treatments	Nitrogen uptake (kg ha^{-1})				Phosphorus uptake (kg ha^{-1})				Potassium uptake (kg ha^{-1})			
	AT	PE	G	S	AT	PE	G	S	AT	PE	G	S
T_1- Control (100 % NPK)	51.32	106.84	62.55	37.87	14.20	22.31	13.97	10.10	50.31	112.42	15.03	93.45
T_2 - 100 % NPK+ IRRC	48.29	95.76	67.92	37.65	13.66	21.75	14.28	11.03	64.72	127.50	22.66	110.83
T_3 - 100 % NPK+ FFYM	67.57	129.94	79.08	55.41	20.44	33.25	16.18	14.52	78.03	148.96	25.74	127.05
T_4 - 100 % NPK+ FIRRC	63.00	127.76	77.37	45.96	18.74	32.47	16.69	14.82	78.48	149.68	28.62	129.09
T_5 - 75 % NPK+ IRRC	42.10	81.44	57.28	31.81	10.38	19.51	12.38	8.81	55.19	116.38	19.50	93.78
T_6 - 75 % NPK+ FFYM	62.57	129.46	77.16	52.38	18.03	33.13	17.17	15.51	66.75	144.94	20.30	119.15
T_7 - 75 % NPK+ FIRRC	60.93	126.03	80.67	51.64	18.01	34.10	19.04	16.82	75.13	157.92	30.52	133.04
T_8 - 50 % NPK+ IRRC	32.60	59.51	47.02	20.59	8.72	15.39	9.14	6.39	47.23	98.73	14.79	80.59
T_9 - 50 % NPK+ FFYM	43.77	79.19	55.51	30.57	12.32	19.06	11.93	8.14	54.22	112.35	15.44	86.30
T_{10} - 50 % NPK+ FIRRC	36.76	69.89	52.38	26.09	10.43	17.82	11.44	7.60	56.96	115.56	20.72	89.75
S.Ed	2.80	7.19	2.60	2.82	1.28	1.97	1.04	1.47	2.54	7.56	1.81	4.32
C.D(p=0.05)	5.90	15.12	5.46	5.93	2.70	4.14	2.19	3.08	5.34	15.87	3.80	9.07

AT- Active Tillering, PE- Panicle Emergence, G- Grain and S- Straw

Table 5 Effect of PGPM consortia, HA and SWE fortified *in situ* Rice residue compost on Cu, Zn, Fe and Mn content of rice

Treatments	Copper ($mg\ kg^{-1}$)				Zinc ($mg\ kg^{-1}$)				Iron ($mg\ kg^{-1}$)				Manganese ($mg\ kg^{-1}$)			
	AT	PE	G	S	AT	PE	G	S	AT	PE	G	S	AT	PE	G	S
T_1- Control (100 % NPK)	12.66	11.24	4.19	6.83	34.32	26.96	21.25	32.76	241.24	193.48	95.09	147.67	100.05	79.71	38.80	95.27
T_2 - 100 % NPK+ IRRC	12.99	12.20	5.14	7.83	36.85	30.63	23.73	36.60	263.98	203.70	96.60	165.59	110.68	87.12	39.69	106.60
T_3 - 100 % NPK+ FFYM	15.59	13.34	5.50	8.03	44.04	34.54	27.04	40.69	284.42	217.16	100.02	174.85	132.68	89.77	43.78	108.91
T_4 - 100 % NPK+ FIRRC	15.15	13.37	5.47	8.37	42.97	34.16	26.26	41.47	281.78	216.16	100.36	175.70	131.90	93.19	44.27	109.34
T_5- 75 % NPK+ IRRC	12.76	11.77	4.93	7.68	36.12	29.64	22.94	36.11	260.68	202.24	96.56	160.13	107.23	83.52	38.91	103.21
T_6 - 75 % NPK+ FFYM	14.24	13.41	5.72	8.41	41.39	35.94	29.03	41.49	279.44	228.51	100.77	178.23	127.36	94.28	46.83	108.57
T_7 - 75 % NPK+ FIRRC	14.18	13.79	5.85	8.81	41.16	37.04	29.40	41.58	274.39	230.47	102.19	178.31	126.13	96.89	47.19	109.52
T_8 - 50 % NPK+ IRRC	12.67	11.72	4.66	7.56	34.49	29.44	22.81	33.55	256.90	200.83	96.11	156.33	107.00	80.07	38.89	100.51
T_9 - 50 % NPK+ FFYM	14.14	13.33	5.38	7.98	38.53	33.23	25.09	39.06	265.08	214.93	99.96	169.36	117.71	89.50	41.51	108.52
T_{10} - 50 % NPK+ FIRRC	13.83	12.58	5.22	7.91	37.62	32.03	24.96	38.88	263.99	204.36	97.40	167.39	112.28	87.42	41.32	108.24
S.Ed	0.42	0.57	0.28	0.45	1.88	1.93	1.26	2.18	7.89	4.73	2.15	5.43	3.28	4.73	2.15	3.82
C.D(p=0.05)	0.88	1.19	0.60	0.96	3.95	4.05	2.65	4.57	16.58	9.94	4.53	11.40	6.90	9.94	4.52	8.02

AT- Active Tillering, PE- Panicle Emergence, G- Grain and S- Straw

Table 6 Effect of PGPM consortia, HA and SWE fortified in situ Rice residue compost on Cu, Zn, Fe and Mn uptake of rice

Treatments	Copper (g ha^{-1})				Zinc (g ha^{-1})				Iron (g ha^{-1})				Manganese (g ha^{-1})			
	AT	PE	G	S	AT	PE	G	S	AT	PE	G	S	AT	PE	G	S
T_1- Control (100 % NPK)	48.03	104.21	21.41	48.34	130.70	250.72	109.01	231.54	914.99	1797.55	486.07	1044.29	381.01	739.39	198.42	673.28
T_2 - 100 % NPK+ IRRC	48.82	113.63	26.54	57.66	138.47	285.12	122.78	269.05	991.98	1897.91	499.39	1220.40	415.64	810.57	205.16	784.56
T_3 - 100 % NPK+ FFYM	69.52	141.98	31.79	67.08	196.47	365.87	156.07	340.03	1271.61	2310.71	577.66	1461.08	591.09	951.18	252.95	910.52
T_4 - 100 % NPK+ FIRRC	64.68	138.42	31.36	69.34	183.80	352.94	150.70	344.31	1203.69	2239.78	576.53	1459.79	562.87	966.33	253.99	906.58
T_5 - 75 % NPK+ IRRC	43.50	101.32	22.81	48.31	122.91	255.48	106.75	227.08	888.80	1745.24	448.39	1006.05	365.02	719.84	181.04	647.88
T_6 - 75 % NPK+ FFYM	60.02	146.53	33.44	70.65	174.34	392.01	169.82	349.17	1177.22	2496.28	589.26	1493.70	536.51	1028.31	273.66	909.99
T_7 - 75 % NPK+ FIRRC	59.28	147.19	35.29	75.42	172.88	395.27	177.15	356.10	1150.56	2460.56	616.03	1528.02	527.24	1035.10	284.71	939.48
T_8 - 50 % NPK+ IRRC	37.14	87.17	18.49	41.24	101.17	218.98	90.61	182.76	753.18	1495.14	381.54	847.78	314.26	595.17	154.76	548.08
T_9 - 50 % NPK+ FFYM	50.83	113.72	24.61	48.76	138.45	284.15	114.64	238.47	953.14	1835.36	457.45	1033.21	422.40	763.85	189.89	663.30
T_{10} - 50 % NPK+ FIRRC	44.78	104.94	22.70	46.23	121.81	268.14	109.00	226.89	853.96	1707.06	424.27	977.93	363.24	729.52	179.71	632.07
S.Ed	2.60	6.75	1.38	4.11	11.38	20.12	8.73	20.97	58.14	98.36	22.99	55.14	23.44	47.15	14.70	37.58
C.D(p=0.05)	5.46	14.20	2.90	8.63	23.91	42.28	18.35	44.06	122.16	206.65	48.30	115.86	49.23	99.05	30.89	78.94

AT- Active Tillering, PE- Panicle Emergence, G- Grain and S- Straw

et al. (1977) and Jagathjothi and Ramamoorthy (2015).

However, at later stages of rice growth the higher content and uptake of micronutrients was noticed in fortified *in situ* rice residue compost which might be due to the slow release of nutrients from rice residue on decomposition resulting in the release of plant nutrients by the process of microbial degradation of rice straw according to the plant demand (Sannathimmappa et al. 2015). The increased uptake in grain and in straw of rice could be due to increased nutrient availability and subsequently reflecting in dry matter accumulation. Similar findings were reported by Kumar and Singh (2010) and Prasad et al. (2010).

The increase in uptake of cationic micronutrients with the application of organic manure along with inorganic nitrogen might be due to the release of micronutrients on mineralization or production of organic acids during the decomposition process by microbes which aids in solubilization of insoluble micronutrient compounds in soil or due to chelating agents which render increased nutrient solubility and availability; thereby playing an important role in increased plant growth and nutrient uptake. This was in accordance with the results of Dahdouh et al. (1999) and Gogoi et al. (2010).

Grain and straw yield

Grain and straw yield of rice were significantly influenced by different treatments (Table 7). Among the treatments, T_7-75% NPK along with FIRRC application recorded the highest grain yield (6.03 t ha^{-1}) and straw yield (8.57 t ha^{-1}). Other treatments, T_6 -75% NPK + FFYM at 5 t ha^{-1}, T_3 - 100% NPK+ FFYM at 5 t ha^{-1} and T_4 - 100% NPK+ FIRRC followed T_7. The lowest grain yield (3.97 t ha^{-1}) and straw yield (5.45 t ha^{-1}) were obtained in T_8, where the plot was applied with 50 per cent NPK and rice residue without fortification. The higher yield of rice in treatments T_7 fortification of PGPM consortia, HA and SWE with *in situ* rice residue compost could be due to the result of rapid decomposition of rice residue by added microbes, resulting in greater nutrient availability, diseasing resistance which leads to improved plant growth and yield. These findings are in conformity with results found by Barus 2012, Jusoh et al. 2013, Sharma et al. 2014, Malusa et al. 2016, Simarmata et al. 2016. Seaweed extract and humic acid contain plant growth regulators such as cytokins, auxin, giberrabillins, betains and also contains macro nutrients as well as micro nutrients. Thus fortification of HA and SWE paves a way for better crop establishment and higher yields as well (Begum et al. 2018; Sandepogu et al. 2019). Application of rice residue compost along with a reduced amount of inorganic fertilizers maintained higher yield of rice. This result is well augmented (Arafah and Sirappa 2003; Watanabe et al. 2013; Watanabe et al. 2017).

Conclusion

The results of the present investigation apparently proved that effective disposal of rice residues by the

Table 7 Effect of PGPM consortia, HA and SWE fortified in situ Rice residue and FYM compost on the yield of rice

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
T_1- Control (100 % NPK)	5.11	7.07
T_2 - 100 % NPK+ IRRC	5.17	7.36
T_3 - 100 % NPK+ FFYM	5.77	8.36
T_4 - 100 % NPK+ FIRRC	5.74	8.30
T_5 - 75 % NPK+ IRRC	4.64	6.28
T_6 - 75 % NPK+ FFYM	5.85	8.39
T_7 - 75 % NPK+ FIRRC	6.03	8.57
T_8 - 50 % NPK+ IRRC	3.97	5.45
T_9 - 50 % NPK+ FFYM	4.57	6.12
T_{10} - 50 % NPK+ FIRRC	4.36	5.84
S.Ed	0.17	0.27
C.D(p=0.05)	0.37	0.56

way of returning into soil along with the combined application of plant growth promoting microbes, humic acid and seaweed extract as fortified *in situ* rice residue compost could significantly increase the soil fertility, nutrient uptake and yield of rice crop. The farmers may substitute 25 per cent of the recommended dose of fertilizer through fortification of organic manures especially rice residue. The fortification of rice residues with PGPM, humic acid and seaweed extract can reduce the nutrients' immobilization that occur during the initial period of rice residue decomposition and supply plant nutrients similar to that of fortified FYM. Thus, FIRRC can be suggested as a cost-effective, eco-friendly technology for sustaining soil properties as well as to increase rice productivity. Further, profundity studies on the use of fortified rice residues compost may be in the directions of its effect on soil microbial population, soil enzymatic activities, and changes in nutrient pool. Induced crop disease resistance will throw insight into rice residue composting in sustaining soil quality and fertility.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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