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Effect of Liquid Microbial Consortium on Physio Chemical Properties of Rice Field (*Oryza Sativa*) in a Vertisol

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A study was conducted during kharif 2020 on "Effect of liquid microbial consortium (*Azotobacter*, *Azospirillum*, PSB (*Pseudomonas mallei*, *Pseudomonas cepaceae*, *Penicillium sp.*) and KSB) on physio chemical properties and microbial population of rice field (*Oryza sativa*) in a V*ertisol*" at the Indira Gandhi Krishi Vishwavidyalaya's Research cum instructional farm in Raipur (C.G.). Experiment included seven treatments *viz.* control (no fertilizer, no liquid NPK microbial consortia), two independent applications of 75 % RDF (90:45:30) and 100% RDF ((120: 60: 40) N, P_2O_5, and K_2O kg ha^{-1} and four various combinations of seed and soil application of liquid NPK microbial consortia. Seed coating with NPK consortia @5ml kg^{-1}, with 75% and 100% RDF and Seed coating with NPK consortia @5ml kg^{-1} + Soil application of NPK consortia @3 L ha^{-1} at 21 DAS with

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75%RDF and 100%RDF. In the experiment, liquid biofertilizer products, such as liquid microbial NPK consortia were used. The population of *Azotobacter*, *Azospirillum*, phosphorous solubilizing bacteria (PSB), potassium solubilizing bacteria (KSB) and total bacterial population were significantly influenced by application of consortia as seed treatment @ 5ml kg-1 only and by a combination of seed treatment @ 5ml kg-1 seed + soil application @ 3 L ha-1 at 21 DAT with 75 or 100 % recommended dose of fertilizers and showed statistically significant higher microbial population in comparisons with the treatments of untreated alone applications of 75 or 100 % RDF. The results showed that the soil reaction, (pH) salt concentration (Electrical conductivity) and organic carbon status were not significantly influenced by the different treatments of fertilizer levels and microbial consortia applied. Slight decrease in the soil reaction (pH) and slight increase in the OC status after the harvesting of rice were observed from their initial soil values (before application of treatments). It might be due to the addition of organic matter as plant residues (straw and roots) of rice crop gown in the field. As compared to untreated- control (T1) a slight decrease in pH and increase in organic carbon content due to application of fertilizer and microbial consortia were also recorded. The residual available nitrogen in the soil after the harvesting of rice was not significantly influenced by the fertilizer levels and NPK consortia applied. The initial status of the experimental soil was low for available nitrogen (224 kg ha-1), medium for available phosphorus (24.5 kg ha-1) and high for available potassium (384 kg ha-1). Due to the addition of nitrogen through the fertilizer (90-120 kg ha-1) and less uptake of native nitrogen from the soil, a marginal increase in the residual available N in the soil from the initial level was observed in all treatments except the control (no fertilizer, no consortia). The residual status of available potassium was also not significantly influenced by the applied fertilizer doses and NPK consortia. A marginal decrease in the residual available K status after the harvesting of rice was observed in all treatments. A decrease was found in the control plot. A decrease in the K status (from the initial level) was observed less where a full dose of NPK fertilizers (100%) was applied with the NPK consortia. Ramlakshmi et al. [1], also observed slight reduction in soil pH and increase in organic carbon content in biofertilizer inoculated treatments as compared to the un-inoculated control soil [2].

Keywords: Liquid microbial consortium; rice field; physio chemical properties; liquid biofertilizer products; soil analysis.

1. INTRODUCTION

Bio-fertilizer is generally defined as a material which contains living microorganism. It contains various types of important micro-organisms include nitrogen fixers, phosphate solubilizing bacteria (PSB) and plant growth promoting rhizobacteria (PGPR). Such as *Azospirillum* and *Azotobacter* can be used as a nitrogen fixer in the crops like rice, sorghum, wheat, maize, mustard, and other vegetable crops. Phosphate solubilising bacteria (PSB) is used in all crops to solubilise and increase availability of soil phosphorous.

It adds nutrients through the natural processes of fixation of atmospheric nitrogen, solubilizing soil phosphorous and stimulating the plant growth through synthesis of growth- promoting substances (Vessey, 2003). Use of bio-fertilizers are an important component of integrated nutrient management for sustainable agriculture. Bio-fertilizers can improve soil physical, chemical, biological characteristics and agricultural production (Yosefi et al*.,* 2011).

The major constraint for rice production in this ecosystem is leaching of nutrients, among which nitrogen and potassium are the most important. Phosphorus deficiency is another important limiting factor of rice production. Though the productivity of rice is low in India, proper, judicious and balanced use of inorganic fertilizers is a main issue to improve the rice productivity. Day by day increasing in cost of chemical fertilizers is also forces the farmers to search for an alternative low-cost resource. In this context bio-fertilizers have gained prime importance. Nitrogen fixing bacteria, *Azospirillum* and phosphate solubilising bacteria has attracted the attention of many scientists for their commercial utilization in rice cultivation. Nitrogen fixing bacteria can fix atmospheric nitrogen and P-solubilizing microbes solubilize phosphate into soluble form [3].

Biofertilizers are generally applied to soil, seeds or seedlings, with or with or without some carrier.

The use of carrier-based bio-fertilizers poses constraints due to low shelf life, poor survival rate, high degree of contamination and low water activity of inoculums. Liquid microbial consortium (Liquid bio-fertilizers) is special liquid formulation containing not only the desired beneficial microorganisms and their biological secretions, but also special cell protestants or substances that encourage the formation of dormant spores or cysts for longer shelf life and tolerance to adverse conditions. Liquid bio fertilizer formulation is the promising and updated technology of the conventional carrier-based productions technology with many advantages over the agrochemicals. Application of liquid bio-fertilizers can aid a major significance in the yield of Rice crop, thus holding great advantage to world's food security. Considering all the facts in mind, the present experiment entitled, **"**Physio chemical properties and microbial populations of rice field (*Oryza sativa*) in a *vertisol*" was carried out during the kharif season of 2020.

Experiment site: The experiment was conducted on Research cum Instructional Farm, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh during kharif season 2020. Raipur is situated between 22^o 33' N to 21^o 14' N latitude and 82^o 6' E to 81^o 38' E Longitude with the altitude of 293m above Mean Sea Level. The exact location of research site i. e. IGKV Farm 21.2514^o N Latitude and 81.6296^o E longitude. The soil of the experimental Rice field (0 to 15 cm depth) was black (*Vertisol*- locally known as "Kanhar") and clayey in texture, with a neutral pH (7.47). The physico-chemical properties of the experimental field were suitable for the rice crop. It was non saline (EC 0.28 dSm^{-1}) and low in organic carbon content (0.59%). The soil was low in available nitrogen (223 kg ha^{-1}), high in available phosphorus (24.4 kg ha^{-1}) and high in available potassium (384 kg ha^{-1})

2. MATERIALS AND METHODS

2.1 Soil Analysis

A representative soil sample was taken from surface (0-15 cm depth) of the field as an initial sample before the transplanting of rice and prepared for analysis of initial characters of experimental soil. After harvesting of the crop, treatment wise surface soil samples (0-15 cm depth) were collected from each plot. Treatments wise soil samples were prepared with wooden rod and sieved with 2 mm sieve. Properly prepared and labelled soil sample were kept for analysis in the laboratory. Soil pH was determined in 1: 2.5 ratio soil- water suspensions [4]. Electrical conductivity (dSm^{-1}) of supernatant liquid was recorded by Electrical conductivity meter [5], Organic carbon (%) was estimated by the Walkley and Black's rapid titration method (1934). Available Nitrogen (kg ha^{-1}) in soil was determined by alkaline potassium permanganate method as described by Subbiah and Asijia [6], phosphorus in the soil was carried out by the method as given by Olsen et al. [7]. Available potassium was determined by extracting soil with neutral normal ammonium acetate solution. The estimation of potassium was carried out by Flame photometer as described by Jackson [8].

2.2 Liquid Microbial Consortium

IFFCO made liquid consortia were used as a testing material in this experiment. It contains nitrogen fixing bacteria, (*Azotobacter /Azospirillum /Rhizobium*), Phosphate Solubilising Bacteria (*Pseudomonas mallei, Pseudomonas cepaceae, Penicillium sp.*) and Potash Solubilising Bacteria (KSB) which CFU (Minimum Count) 1 X 10^{-8} per ml with the total viable count- 5 X 10^{-8} cells per ml.

2.3 Treatment Detail

Experiment consist of seven treatments, viz. T1-Control (0:0:0), T2- 75% RDF (90:45:30), T3-100% RDF (120:60:40), T4-75% RDF + Seed coating with NPK Liquid Microbial Consortia @5ml kg^{-1}, T5- 100% RDF + Seed coating with NPK Liquid Microbial Consortia @5ml kg^{-1}, T6-75% RDF + Seed coating with NPK Liquid Microbial Consortia @5ml kg^{-1} + Soil application of NPK consortia @3 L ha^{-1} at 21 DAS, and T7-100% RDF + Seed coating with NPK Liquid Microbial Consortia @5ml kg^{-1} + Soil application of NPK Liquid Microbial Consortia @3 L ha^{-1} at 21 DAS. with three replications were used in a complete randomized block design.

2.4 Data Analysis

Data were collected through various observations of soil on different dates was carried out in split plot design with two levels each replicated three times as described by Gomez and Gomez (1984). Test of significance of the treatments were computed with the critical difference at 5 percent level of significance.

3. RESULTS AND DISCUSSION

3.1 Effect of Liquid Microbial Consortium on Biological Properties of the Soil

Azotobacter: The obtained result (Table 1) shows that the maximum population of *Azotobacter* in the rhizosphere soils was observed treatment with microbial consortia (seed treatment or soil application). Data shows that among the treatments of application of consortium with 75% RDF (T4 and T6), Treatment-T6 (130.33 cfu g^{-1} population of *Azotobacter)* were found at par with T4 (115.67 cfu g^{-1}). Both the treatments were observed significantly superior over the alone application of 75% RDF (67 cfu g^{-1}) which showed significant effect of addition of consortia with 75% of RDF as seed coating @ 5ml/ kg (T4) and seed + soil application (T6). It might be due to the application of microbial inoculants through the liquid consortia which enhanced the soil biological activity and significant increase of microbial population in the soil. Similar results were also reported by many scientists. Sah et al. [9] maximum microbial population viz., Bacteria, Actinomycetes, Fungi, *Azospirillum*, PSB and KSB (71.66, 27.33, 57.66, 43.66, 63.00 and 47.66 cfu × 105 g $^{-1}$ oven dry soil) with application of *Azospirillum* + PSB + KSB +100 % recommended dose of N and significantly lower microbial populations with the recommended dose of fertilizer (RDF). Fitriatin et al. [10] revealed that the application of biofertilizers and organic ameliorants significantly improved the soil biological properties and increase the population of N-fixing bacteria.

Azospirillum: The population of nitrogen fixing microorganisms in the rhizosphere soil of the experimental field (Table 1) showed that maximum population of *Azospirillum* 359.67 CFU/gram soil was obtained with T6 (75% RDF + Seed coating with NPK liquid consortia @ 5ml/ kg + Soil application of consortia @ 3 L/ha at 21 DAS) followed by T7, T5, T4, T1, T2 and T3. Among all the treatments, minimum population of *Azospirillum* (272.0) cfu g^{-1}) was found with the treatment T3 (untreated, 100% RDF). The application of consortia with 75% and 100% RDF (seed treatments in T4 and T5 and seed+ soil application in T6 and T7), T6 was recorded maximum population of *Azospirillum* followed by T7, T4 and T5. All these treatments T4- T7 were found at par with each other due to inoculation of *Azospirillum* same result was also reported by Kundu and Gaur [11] and Suliash and Widawati [12].

Table 1. Effect of NPK liquid bio-fertilizer consortium on *Azotobacter*, *Azospirillum*, PSB, KSB and total microbial population in the soil

Treat	Treatment details	Microbial population (cfu g^{-1} soil)				
		Azotobacter **(10^6)**	***Azospirillum*** **(10^6)**	**PSB (10^5)**	**KSB (10^4)**	**Total Bacterial Population (10^8)**
T1	Control (0:0:0)	82.67^{bc}	272.00^{bc}	16.33^{bc}	29.33bc	28.33c
T2	75% RDF (90:45:30)	67.00^{c}	268.67^{bc}	15.33^{c}	28.33c	26.67c
T3	100% RDF (120:60:40)	66.00^{c}	227.33^{c}	12.67^{c}	24.33d	26.00c
T4	75% RDF + Seed coating with NPK consortia @ 5ml/kg	115.67^{a}	340.00^{ab}	21.33^{ab}	36.67abc	39.67b
T5	100% RDF + Seed coating with NPK consortia @ 5ml/kg	96.33^{b}	331.67^{ab}	24.00^{a}	30.67abc	35.67bc
T6	75% RDF + Seed coating with NPK consortia @ 5ml/kg + Soil application of NPK consortia @ 3 L/ha at 21	130.33^{a}	359.67^{a}	26.67^{a}	39.00a	60.33a

Treat	Treatment details	Microbial population (cfu g^{-1} soil)				
		***Azotobacter* (10^6)**	***Azospirillum* (10^6)**	**PSB (10^5)**	**KSB (10^4)**	**Total Bacterial Population (10^8)**
	DAS					
T7	100% RDF + Seed coating with NPK consortia @ 5ml/kg + Soil application of NPK consortia @ 3 L/ha at 21 DAS	118.33^{a}	342.67^{ab}	24.67^{a}	36.67ab	55.67a
	CD at 5%	17.14	76.08	5.71	9.22	10.49
	SEM±	5.562297	24.69105	1.85164	2.99337	3.40472
	CV %	9.97	13.97	15.92	17.03	15.15

Table 2. Some important initial physio-chemical properties of the soil under study

Sl. No.	Properties	Value	Status
1.	Mechanical compositions		
	Sand (%)	24	
	Silt (%)	27	Clay texture
	Clay (%)	48	
2.	pH – (1:2.5)	7.47	Neutral
3.	EC – (dSm^{-1})	0.28	Normal
4.	Organic Carbon (%)	0.59	Medium
5.	Available Nitrogen (Kg ha^{-1})	223	Low
6.	Available Phosphorus (Kg ha^{-1})	24.4	Medium
7.	Available Potassium (Kg ha-1)	384	High
8.	Soil Micronutrient (ppm)		
	Available Zn	1.61	Sufficient
	Available Mn	6.9	Sufficient
	Available Cu	2.6	Sufficient
	Available Fe	10.5	Sufficient

Table 3. Effect of microbial consortium on soil pH, EC, and OC status in soil after harvesting

Treat.	Treatment	pH	EC (dSm^1)	OC (%)
T1	Control (0:0:0)	7.30	0.27	0.59
T2	75% RDF (90:45:30)	7.29	0.26	0.59
T3	100% RDF (120:60:40)	7.27	0.26	0.60
T4	75% RDF + Seed coating with NPK consortia @ 5ml kg^{-1}	7.27	0.25	0.58
T5	100% RDF + Seed coating with NPK consortia @ 5ml kg^{-1}	7.25	0.25	0.61
T6	75% RDF + Seed coating with NPK consortia @ 5ml kg^{-1} + Soil application of NPK consortia @ 3 L ha^{-1} at 21 DAS	7.26	0.26	0.59
T7	100% RDF + Seed coating with NPK consortia @ 5ml kg^{-1} + Soil application of NPK consortia @ 3 L ha^{-1} at 21 DAS	7.25	0.26	0.60
	CD at 5%	**NS**	**NS**	**NS**
	SEM±	0.0437	0.0125	0.0151

Phosphate solubilising bacteria (PSB): Among the treatments of applications T2 and T3, population of PSB were recorded 15.33 and 12.67 cfu g^{-1}, respectively, and found at par with each other. The application of consortium with 75% RDF T4 (seed coating) were found at par with 6 (seed coating + soil application) with 21.33 and 26.67 cfu g^{-1} population of PSB, respectively. Both T4 and T6 were significantly higher population of PSB over alone application of 75% RDF (T2) which shows significant effect of additions of consortia. Treatments of consortia with the 100% RDF (T5) and (T7) (Seed coating + soil application) and T5 (Seed coating) were found at par with each other with 24.67 and 24.00 cfu g^{-1} population of PSB, respectively, which shows similar increase in population of PSB due to addition of consortia as seed treatment or combined as seed + soil application with the full dose of RDF. Both the treatments were also found significantly higher population of PSB over the control and 100 % RDF (T3) which shows the application of PSB inoculants through the NPK consortia enhanced the soil biological activity and increased the microbial population in the soil. Similar finding reported by Fitriatin et al. [9], they found that the application of biofertilizers and organic ameliorants significantly improved the soil biological properties and increase the population of phosphate solubilizing microbes and phosphatase activity in the soil [13].

KSB (Potash solubilizing bacteria): The results of effect of consortia on population of potassium solubilising bacteria in the rhizosphere soil showed that the population of KSB was significantly influenced by the application of liquid microbial consortia. Treatments of microbial consortia with 75 or 100 % recommended dose of fertilizers showed statistically significant higher population of KSB in comparisons with the untreated or alone applications of 75 or 100 % RDF. Application of consortia as seed treatment @ 5ml/ kg seed and as combination of seed treatment and soil application @ 3 L/ha at 21 DAT with 75 or 100 % RDF, all the treatments were found similar effective to the increase in the KSB population in the soil. It might be due to the application of KSB inoculants through the NPK consortia which were multiply and increased the microbial population in the soil. Sah et al., [9], the addition of biofertilizers and organic ameliorant significantly increased the soil biological properties. They found maximum microbial population of PSB and KSB with the application of *Azospirillum* + PSB + KSB +100 % RDN and recorded significantly lower microbial populations with the recommended dose of fertilizer (RDF).

Total bacterial population: Effect of consortia on the total bacterial population in the rhizosphere soil showed that the total bacterial population was significantly influenced by the application of liquid microbial consortia. Treatments of microbial consortia with 75 and 100 % recommended dose of fertilizers showed statistically significant higher bacterial in comparisons with the untreated alone applications of 75 or 100 % RDF. Application of consortia in combination of seed treatment @ 5ml/ kg seed + soil application @ 3 L/ha at 21 DAS with the 75 or 100 % RDF were found more effective to increase the total bacterial population in the soil as compare to only seed treated plots. Ramlakshmi et. al. [1], also reported that soils of the biofertilizer inoculated plots exhibited a higher population of total bacteria, fungi and actinomycetes in general than initial sample indicating an enhanced soil biological activity. Similar results were also found by Kumar et al. [14], Meena et al. [15] and Sah et al. [9].

3.2 Soil Physio Chemical Properties

Effect of microbial consortium on soil pH, EC and OC content (%): Soil reaction (pH) salt concentration (Electrical conductivity) and organic carbon status were not significantly influenced by the different treatments of fertilizer levels and microbial consortia applied. Slightly decrease in the soil reaction (pH) and slightly increased in the OC status after the harvesting of rice were observed from their initial soil values. It might be due to the addition of organic matter as plant residues (straw and roots) of rice crop gown in the field. As compared to untreated-control (T1) a non-significant decrease in pH and increase in organic carbon content due to application of fertilizer and microbial consortia were also recorded. Ramlakshmi et. al. [1] also observed slightly reduction in soil pH and increase in organic carbon content in biofertilizer inoculated treatments as compared to the un-inoculated control soil.

Changes due to NPK liquid bio fertilizer consortia on N, P and K status: After one year of experiment, the results of effect of fertilizer levels and on pH, EC, and organic carbon status of the soil showed that the soil reaction (pH) and salt concentration (Electrical conductivity) were not significantly influenced by the fertilizer levels and microbial consortia applied (as seed

Table 4. Effect of liquid NPK consortia on soil available N, P and K after harvesting of rice

Treat.	Treatment	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T1	Control (0:0:0)	219.89	21.82b	370.3
T2	75% RDF (90:45:30)	225.79	24.69ab	376.3
T3	100% RDF (120:60:40)	228.73	27.11a	379.5
T4	75% RDF + Seed coating with NPK consortia @ 5ml/kg	224.85	24.84 ab	372.6
T5	100% RDF + Seed coating with NPK consortia @ 5ml/kg	227.94	26.95a	377.1
T6	75% RDF + Seed coating with NPK consortia @ 5ml/kg + Soil application of NPK consortia @ 3 L/ha at 21 DAS	226.94	25.42a	374.1
T7	100% RDF + Seed coating with NPK consortia @ 5ml/kg + Soil application of NPK consortia @ 3 L/ha at 21 DAS	226.55	27.68a	375.3
	CD at 5%	**NS**	**3.54**	**NS**
	SEM±	**2.9984**	**1.1486**	**7.0079**
	CV %	**2.29**	**7.80**	**3.24**
	Initial values kg/ha	**223.70**	**24.36**	**384.44**

treatment and soil application). No significant difference in the soil organic carbon status was also observed among the various treatments after one-year experimentation. Organic carbon content in the soil was ranged 0.58 to 0.61% with no significant differences. No changes in the above parameters may be due to the first year of application of microbial consortia; in the long term, it may show any significant effect.

Available nitrogen: The residual status of available nitrogen in the soil after the harvesting of rice was not significantly influenced by the fertilizer levels and microbial consortia applied. Among all the treatments, maximum available nitrogen (228.7 kg ha^{-1}) was recorded with application of 100% RDF @ 120:60:40 kg ha^{-1} (T3), while minimum soil available nitrogen (219.9 kg ha^{-1}) was found with the control (T1).

The data showed no significant variation in the residual available nitrogen status due to the application of microbial consortia with the chemical fertilizer at either 75% RDF or 100% RDF. Values of soil nitrogen were observed to be higher in the 100% RDF and 75% RDF applied treatments (T2-T7) than the control. The treatments T2-T7 showed a marginal increase in residual available N in the soil from the initial level (223.7 kg ha^{-1}). It might be due to the addition of nitrogen through the fertilizer (90-120 kg ha^{-1}) and less uptake of nitrogen from the soil, leading to a substantial amount of leftover N nutrient in the soil, while due to no application of nitrogen fertilizer and uptake from the stored soil nitrogen, the lowest value was recorded with the treatment of T1 (control). Due to the low yield and overall, less uptake of soil nitrogen in the control plot.

Positive effect of inorganic fertilizers and consortium biofertilizers on fertility status of the soil was reported by various scientists *viz.* Maragatham and Martin, [16], Yuvaraj, [17], Ramlakshmi et. al., [1], that application of 100 percent RDF + biofertilizers increased the availability of nitrogen as compared with control. Also reported that status of soil available nitrogen was higher in the treatments where *Azospirillum* was a component as compared to control and observed statistically higher nitrogen in the treatment having inorganic fertilizers and consortium biofertilizers. Shaban et al. [18] observed, biofertilizers significantly increased N,P and K content in plant and also increased Fe, Mn, Zn, and Cu concentration in soil.

Available phosphorus: Data on Table 4. shows that residual available phosphorus in the soil after harvesting of rice was significantly influenced by the fertilizer levels and microbial consortia. The maximum residual available phosphorus (27.7 kg ha^{-1}) in the soil was observed in treatment of combined application of consortia as seed treatment + soil application with 100% RDF (T7), while the minimum available phosphorus (21.8 kg ha^{-1} P) was found in control treatment (T1). Among the various treatments of application of chemical fertilizers (T2 and T3), 100% of the recommended dose of fertilizer (27.1 kg ha^{-1} P) was found at par residual available phosphorus with 75% of the RDF (24.7 kg ha^{-1} P) and observed significantly higher than the control (21.8 kg ha^{-1} P). Among the various treatments of microbial consortia (seed treatment + soil application) with the 75% RDF, the residual available phosphorous of T4 (24.8 kg ha^{-1}) and T6 (25.4 kg ha^{-1}) were observed at par with each other. They also found at par residual soil P with the 75% RDF alone (24.7 kg ha^{-1}) and 100% RDF alone (T3) which shows that application of 75% RDF + Seed coating with NPK consortia @ 5ml/kg (T4) and 75% RDF + Seed coating with NPK consortia @ 5ml kg^{-1} + Soil application of NPK consortia @ 3 L ha^{-1} at 21 DAS (T6) were found best for manage the residual available phosphorous in the soil and save 25% phosphorous fertilizer.

The residual available phosphorous in the treatments of consortia with 100% RDF (T5 and T7) were found at par with each other and also with alone application of 100% RDF (27.1 kg ha^{-1}). These treatments recorded 27.7 (T7) and 26.9 kg ha^{-1} (T5) soil available phosphorus which showed marginal increase in soil available P from the initial level (24.36 kg ha^{-1}) due to higher dose (100%) of applied phosphorous.

Applications of microbial NPK consortia with 100% RDF (@ 60 kg ha^{-1} P) showed higher residual phosphorous value than the treatments where microbial NPK consortia were applied with 75% RDF (@ 45 kg ha^{-1} P) this might be due to greater addition of inorganic nutrients to the soil.

The results are supported by finding of many scientists. Significant variation in the residual available phosphorus in the soil was also reported by Maragatham and Martin, [16], they also found highest and at par availability of phosphorous in application of 100 per RDF and 100 per cent RDF + biofertilizers. Ramlakshmi et. al., [1], also reported increased available phosphorus in the soil due to application of phosphobacteria. Sreedevi, (2014), revealed that applications of 75 per cent recommended dose of nitrogen and phosphorus along with *Azospirillum* + PSB were found to be the best schedule with saving of 25 per cent of N and P requirement.

Available potassium: Among all the treatments, maximum available potassium (379.5 kg ha^{-1}) was recorded with T3 (100% RDF alone), while minimum soil available potassium (370.3 kg ha^{-1}) was found with control (T1). Values of soil potassium were observed to be higher in the treatments of 75% RDF (T2) and 100% RDF (T3) than in the control (T1). It might be due to the addition of potassium through the fertilizer (30-40 kg ha^{-1}) and less uptake of potassium from the soil, leading to a substantial amount of left-over K nutrient in the soil (treatments T2-T7), while due to no application of potassium fertilizer and uptake from the stored soil potassium, the lowest value was recorded with the treatment of no fertilizer application (control). Due to the low yield and over all less uptake of soil potassium in the control plot (in comparison with other treatments). The treatments showed a marginal decrease in residual available K in the soil from the initial level (284.4 kg ha^{-1}) might be due to the uptake of potassium from the soil. A decrease in the K status (from the initial level) was observed less where a full dose of NPK fertilizers (100%) was applied. The results were also supported by Sreedevi, (2014) and Yuvaraj, [17].

4. CONCLUSION

The population of *Azotobacter*, *Azospirillum*, phosphorous solubilizing bacteria (PSB), potassium solubilizing bacteria (KSB) and total bacterial population were significantly influenced by application of consortia as seed treatment @ 5ml/ kg only and by a combination of seed treatment @ 5ml/ kg seed + soil application @ 3 L/ha at 21 DAT with 75 or 100 % recommended dose of fertilizers and showed statistically significant higher microbial population in comparisons with the treatments of untreated alone applications of 75 or 100 % RDF.

It might be due to the addition of NPK microbial consortia in soil which leads to an increase in microbial population and activity due to more amounts of available carbon and nutrients like N and P to soil microorganism which provide more energy. Later on, the nutrients were exhausted due to crop uptake which reduces the microbial population in soil. It may also be due to secretion of various root exudates by rice roots, utilized by the bacteria for their carbon requirement and leads to increase in multiplication of the microbial population. The microbial inoculants significantly increased bacterial population in soil after harvesting crop over recommended dose of N, P and K. The addition of combined inputs of NPK RDF and microbial consortia enhanced the microbial counts in soil, which might be due to carbon addition and changes in physico-chemical properties of soil.

The results show after one year of experiment, the of effect of liquid NPK consortia on the soil reaction, such as pH, and salt concentration in the soil, such as electrical conductivity, were not significantly influenced by the fertilizer levels and NPK consortia applied. The residual soil fertility also exhibited that after the one-year experimentation, there were no significant differences in the soil organic carbon status were recorded among the treatments. The application of NPK consortia with 100% RDF resulted in the highest soil organic carbon (0.60- 0.61%), while the lowest organic carbon (0.58- 0.59%) was found with the control and lower fertilized treatments. No changes in the above parameters may be due to the first year of application of liquid NPK microbial consortia; in the long term, it may show a significant effect.

The residual available nitrogen in the soil after the harvesting of rice was not significantly influenced by the fertilizer levels and NPK consortia applied. The initial status of the experimental soil was low for available nitrogen (224 kg ha^{-1}), medium for available phosphorus (24.5 kg ha^{-1}) and high for available potassium (384 kg ha^{-1}). Due to the addition of nitrogen through the fertilizer (90-120 kg ha^{-1}) and less uptake of native nitrogen from the soil, a marginal increase in the residual available N in the soil from the initial level was observed in all treatments except the control (no fertilizer, no consortia). The residual status of available potassium was also not significantly influenced by the applied fertilizer doses and NPK consortia. A marginal decrease in the residual available K status after the harvesting of rice was observed in all treatments. A decrease was found in the control plot. A decrease in the K status (from the initial level) was observed less where a full dose of NPK fertilizers (100%) was applied with the NPK consortia [19-21].

Residual available phosphorus in the soil after harvesting of rice was significantly influenced by fertilizer and NPK consortia applied. Except for the control, all treatments found at par and showed a marginal increase in soil available P from the initial level. Applications of NPK consortia with 100% RDF (@ 60 kg ha^{-1} P) showed higher residual available phosphorous (26.9–27.7 kg $ha^{-1)}$ than the treatments where liquid microbial consortia were applied with 75% RDF (ranged from 24.8–25.4 kg ha^{-1} available P). All these treatments of NPK consortia with 75 and 100% RDF were observed to have equal residual available phosphorous with each other and showed at par with application of 75 % RDF (24.7 kg ha^{-1} P) and 100% RDF (27.11 kg ha^{-1} P).

Over all, maximum residual available phosphorus (27.68 kg ha^{-1}) was obtained with the application of 100% RDF + Seed coating with NPK consortia @ 5ml kg^{-1} + Soil application of NPK consortia @ 3 L ha^{-1} at 21 DAT (T11), while the minimum available phosphorus (21.82 kg ha^{-1} P) was found in the control. Hence application of NPK consortia with 75% RDF (T4 and T6) can manage residual available phosphorous in the soil and save 25% phosphorous fertilizer.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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