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Nutrient Uptake, Soil Fertility Status and Nutrient Use Efficiency of Rice as Influenced by Inorganic and Bio-fertilizer in New Alluvial Zone of West Bengal

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Authors' contributions

This work was carried out in collaboration between both authors. Author MM collected the data, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author AS assisted in the analyses of the study and refined the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: To study the influence of inorganic and bio-fertilizers on nutrient uptake, soil fertility status and nutrient use efficiency of rice (*Oryza sativa* L.).
Place and Duration of Study: The field trial was conducted in the experimental farm of Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India during *kharif* season of 2016.
Methodology: The experiment was carried out in a randomized block design with seven treatments each of which was replicated three times. The experiment was comprised of seven treatments *viz*. T_1: control, T_2: chemical fertilizer at 100% recommended dose of NPK, T_3: 50% recommended dose of NP + 100% RDK + *Bacillus polymyxa*, T_4: 75% recommended dose of NP + 100% RDK + *Azotobacter chroococcum*, T_5: 75% recommended dose of NP + 100% RDK +

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Bacillus polymyxa, T_6: 50% recommended dose of NP + 100% RDK + *Pseudomonas fluorescence* and T_7: 50% recommended dose of NPK + *Bacillus polymyxa*. Rice cultivar 'IET-4786 (Shatabdi)' was used as test crop.
Results: Results of this study revealed that the maximum nutrient concentration in rice grain and straw; total N, P and K uptake (136.80, 37.07 and 184.65 kg ha^{-1} respectively); grain and straw yield; were obtained with the application of 100% recommended dose of chemical fertilizer (T_2). T_2 treatment was followed by 75% recommended dose of NP + 100% RDK + *Azotobacter chroococcum* (T_4) and 75% recommended dose of NP + 100% RDK + *Bacillus polymyxa* (T_5). Treatments T_4 and T_5 were significant in improving the soil health status including organic carbon content (0.38%), available N (183.29 and 172.43 kg ha^{-1}), P_2O_5 (44.31 and 41.46 kg ha^{-1}) and K_2O (217.89 and 195.82 kg ha^{-1}).
Conclusion: Therefore, treatments T_4 and T_5 exhibited beneficial effect on improving soil health and nutrient use efficiency leading towards higher rice yield along with reducing soil deterioration and maintaining sustainability.

Keywords: Bio-fertilizer; inorganic fertilizer; nutrient uptake; nutrient use efficiency; rice; soil health.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is an important cereal crop in the developing world and meets the dietary energy requirements for almost half of the world's population with a high caloric value (78.2% carbohydrate, 6.8% protein, 0.5% fat and 0.6% mineral matter). The crop is grown in 43 million hectares of land with production of 96.7 million tons in India but to meet the over expanding demand, the production has to be raised to 160 million tons by 2030 with a minimum annual growth rate of 2.35% [1]. One of the major constraints of crop production in developing countries is the unavailability of nutrients in appropriate amount and form [2]. Modern agricultural practices generally emphasized widespread use of synthetic fertilizers which certainly increased grain yields in the last six decades. However, long term use of chemical fertilizers led to a decline in crop yields as well as soil fertility in the intensive cropping systems [3]. Indiscriminate and continuous use of chemical fertilizers lead to instability in yield and also pose a threat to soil health particularly due to micronutrients deficiency and fertilizer related environmental pollution [4]. Moreover, the produce so developed may raise a question about its quality and acceptability in market. This has in turn paved the way for using different nutrient sources. The emerging scenario necessitates the need of adoption of the practices which maintain the soil health, keep the production system more sustainable and provide qualitative food for meeting the nutritional requirements. Therefore, an increased level of yield with reduced environmental risk while maintaining the soil health at the same time require new cultivation strategies that incorporate the use of biological fertilizers [5]. The bio-fertilizer is a natural input that can be applied as a complement to or as a substitute of chemical fertilizer in sustainable agriculture [6]. Integrated use of bio-fertilizers offers a cheaper, low capital intensive and eco-friendly route to boost farm productivity [7]. Role of bio-fertilizers for enhancing the productivity of soil either by fixing atmospheric N or solubilising soil P or by stimulating plant growth through synthesis of growth promoting substances is well known and has gained special importance in crop production including rice. It is reported that the available N, P and K contents were increased significantly with the application of bio-fertilizers along with chemical fertilizers [8]. Integrated use of bio-fertilizers and chemical fertilizers significantly improved the available N and P and K contents of soil compared to sole application of chemical fertilizers [9].

So, there is an urgent need to study the impact of different types of fertilizers in partially compensating the higher demand of chemical fertilizers for growing rice varieties to improve nutrient uptake, nutrient use efficiency and soil fertility status. Therefore, considering all the factors, the present study was carried out to develop a cost effective eco-friendly sustainable system where the supply of nutrients to plants can be ensured.

2. MATERIALS AND METHODS

2.1 Study Area

The experiment was conducted during the *kharif* season of 2016 at 'C' block farm of Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal. The experimental farm was situated at 22.5°N latitude and 89.0°E longitude and at an elevation of 9.75 m above mean sea level. The soil of the experimental field was new alluvial (type – Entisol) and sandy loam in texture with pH 6.81 and had good water holding capacity and moderate fertility. The sand, silt and clay content of the soil were 54.8%, 21.8% and 23.1% respectively and the bulk density was 1.31 g cm^{-3}. On the other hand, the organic carbon, available N, P and K content were 0.30%, 264.52 kg ha^{-1}, 53.60 kg ha^{-1} and 286.28 kg ha^{-1}, respectively.

2.2 Sampling Method and Data Analysis

The experiment consisted of seven treatments *viz.* T_1: control, T_2: chemical fertilizer at 100% recommended dose of NPK, T_3: 50% recommended dose of NP + 100% recommended dose of K (RDK) + *Bacillus polymyxa*, T_4: 75% recommended dose of NP + 100% RDK + *Azotobacter chroococcum*, T_5: 75% recommended dose of NP + 100% RDK + *Bacillus polymyxa*, T_6: 50% recommended dose of NP + 100% RDK + *Pseudomonas fluorescence* and T_7: 50% recommended dose of NPK + *Bacillus polymyxa*. The experiment was conducted in randomized block design with 3 replications [10]. The size of each plot was 5 m x 3 m. Rice cultivar 'IET-4786 (Shatabdi)' was sown. The recommended dose of N: P_2O_5: K_2O for rice was 60: 30: 30 kg ha^{-1} and the chemical fertilizer in the form of urea, single super phosphate (SSP) and muriate of potash (MOP) were broadcasted and incorporated into 15 cm depth of soil. Half dose of N and full dose of P_2O_5 and K_2O were applied as basal; the remaining half N was top dressed at 30 days after transplanting (DAT). All the bio-fertilizers were applied @ 5 kg ha^{-1} as seed treatment. For raising of seedlings about 50 kg seeds of rice were broadcasted in the 4th week of June in nursery bed for transplanting and about 21 days old seedlings were transplanted in 3rd week of July at a spacing of 20 cm × 15 cm. Plant samples at harvest were collected for dry matter accumulation and were analysed for N, P and K content. Soil samples were collected from five randomly selected spots of the experimental field (rhizosphere zone *i.e.* depth up to 15 cm) before transplanting and after harvest and analysed for different physical and chemical properties following the standard procedure. The organic carbon content by wet digestion method [11] and available potassium were measured [12]. Available soil N and P were also estimated [13]. Total N, P and K content in plants were analysed by Micro Kjeldhal digestion method by Jackson [12], Spectrophotometric method by Black [14] and Flame photometric method by Hesse [15] respectively after harvesting of the plant.

Different measures of nutrient use efficiency *i.e.* partial factor productivity (PFP), agronomic efficiency (AE), apparent recovery efficiency (AR), physiological efficiency (PE) and internal utilization efficiency (IUE) and nutrient uptake; were calculated by following formulas.

$$\text{Nutrient uptake} = \frac{\text{Nutrient concentration (\%)}}{100} \times \text{Biomass (kg ha}^{-1}\text{)}$$

$PFP = Y/F$
$AE = (Y-Y_0)/F$
$AR = (U-U_0)/F$
$PE = (Y-Y_0)/ (U-U_0)$
$IE = Y/U$

Where, Y = yield of harvested portion of crop with nutrient applied; Y_0 = yield with not nutrient applied; F = amount of nutrient applied; U = total nutrient uptake in above ground crop biomass with nutrient applied; U_0 = nutrient uptake in above ground crop biomass with no nutrient applied.

The data obtained were subjected to statistical investigation following the analysis of variance technique by using software packages of MS Excel and OPSTAT. Statistical significance between means of individual treatments was assessed using Fisher's Least Significant Difference (LSD) at 5% level of probability.

3. RESULTS

3.1 Nutrient Concentration in Rice Grain and Straw

Nitrogen content in grain and straw: Nitrogen content in rice grain and straw ranged from 1.04 to 1.29% and 0.73 to 0.92%, respectively. The highest N content (1.29%) in rice grain and (0.92%) in rice straw was observed in the treatment T_2 due to application of recommended dose of chemical fertilizer and the lowest N content in grain (1.04%) and in straw (0.73%) was noted in T_1 (control) treatment (Table 1). There was ($p<0.05$) effect of bio-fertilizer and chemical fertilizer on N content in grain and straw and the results revealed that N content in rice grain was higher than straw. According to critical difference value, T_2 treatment was superior over all other treatments. Increase in N content in rice grain and straw due to the application of organic and inorganic fertilizers has been reported by many investigators [16,17].

Phosphorus content in grain and straw: Phosphorus content in rice grain and straw ranged from 0.19 to 0.43% and 0.10 to 0.18% respectively. The highest P content (0.43%) in grain was observed in the treatment T_2 which was at par with T_4 treatment (75% recommended dose of NP + 100% RDK + *Azotobacter chroococcum* @ 5 kg ha^{-1}). In straw, the maximum P concentration (0.18%) was recorded in T_2, T_4 and T_5 treatments being similar with T_3 and T_6 treatments but the lowest P concentration was noted in treatment T_1 (control) for both the cases (Table 1). Incorporation of organic manure increased the concentration of P in rice grain and straw yields of rice [18].

Potassium content in grain and straw: The highest K content in rice grain (0.65%) and straw (2.12%) was observed in the treatment T_2 (100% RDF) that was higher than rest of the treatments and the lowest K concentration in grain and straw (0.39% and 1.32% respectively) was noted in the treatment T_1 (Table 1). From the results, it was clearly observed that the K content in rice straw was higher than grain in all the treatments. K content both in grain and straw of rice increased due to combined application of organic and chemical fertilizers [19,20].

3.2 Nutrient Uptake

Nitrogen uptake: Results in Tables 2 and 3 indicated that the N uptake varied due to the renewed application of inorganic fertilizer and bio-fertilizer. The highest N uptake by rice grain (72.74 kg ha^{-1}) and straw (64.06 kg ha^{-1}) as well as total N uptake by rice plant (136.80 kg ha^{-1}) were recorded in the treatment T_2 (100% RDF) which were different from all other treatments. The lowest uptake by grain and straw (49.02 and 42.74 kg ha^{-1}, respectively) were exhibited by the control plots (T_1). Similar trend was exhibited in case of total N uptake. T_2, T_4 and T_5 treatments recorded 48.39%, 33.03% and 29.64% more N uptake by rice grain and 49.88%, 38.28% and 25.85% more uptake by straw than control. While considering total N uptake, T_2, T_4 and T_5 treatments recorded 49.08%, 35.47% and 27.88% higher N uptake than T_1.

Phosphorus uptake: Phosphorus uptake by rice grain and straw was influenced due to various treatments used in the experiment (Tables 2 and 3). The P uptake by rice grain ranged from 8.83 to 24.47 kg ha^{-1} and by rice straw varied in between 5.69 and 12.72 kg ha^{-1}. The highest P uptake by grain (24.47 kg ha^{-1}) was recorded in the treatment T_2 which was superior to rest of the treatments and the lowest value (8.83 kg ha^{-1}) was observed in the treatment T_1. The P uptake by straw was maximum in case of treatment T_4 (75% recommended dose of NP + 100% RDK + *Azotobacter chroococcum* @ 5 kg.ha^{-1}) which showed similarity with T_2 and T_5 treatments. On the other hand, the total P uptake was highest (37.07 kg ha^{-1}) in 100% chemically fertilized plots and lowest (14.52 kg ha^{-1}) in control treatments.

Potassium uptake: The highest K uptake by rice grain (36.67 kg ha^{-1}) and straw (147.98 kg ha^{-1}) and the total maximum K uptake by rice plant (184.65 kg ha^{-1}) were recorded in the treatment T_2 followed by T_4 and T_5 treatments, and the lowest values (18.45, 77.61 and 96.05 kg ha^{-1} respectively) were observed in the treatment T_1 (Tables 2 and 3). Greater K uptake by rice plants was observed using organic source of nutrients in combination with chemical fertilizers [21].

3.3 Grain and Straw Yield

Grain yield and straw yield were influenced by different fertilizer sources. The grain yield was maximized in T_2 treatment (5660 kg ha^{-1}), which was at par with T_3 (5320 kg ha^{-1}), T_4 (5480 kg ha^{-1}) and T_5 (5400 kg ha^{-1}) treatments. The lowest grain yield (4720 kg ha^{-1}) was observed in case of control treatment (T_1). On the other hand, the application of 100% recommended dose of inorganic fertilizer recorded the maximum straw yield (6990 kg ha^{-1}) and it was also at par with T_4 treatment (6930 kg ha^{-1}). A field experiment was conducted with rice variety ADT-31 where foliar spray of *Azotobacter chroococcum* was applied on 15th, 30th and 45th day after transplanting of rice crop. They observed that the foliar spray of *Azotobacter* culture significantly increased the grain and straw yield of rice crop [22]. The lowest 5880 kg ha^{-1} straw yield was observed in control.

3.4 Post Harvest Soil Properties

The data presented in Table 4 clearly depicted the overall scenario of soil fertility status of the experimental field after harvest of crop in the year of experimentation. Application of bio and chemical fertilizers resulted in considerable influence on the properties of post-harvest soils. In some treatments (T_1, T_4 and T_6) the pH value decreased as compared to the initial value (6.81) but in rest of the treatments such as T_2, T_3, T_5

and T_7, pH value increased. Besides, the electrical conductivity showed higher values in T_2, T_3, T_5 and T_7 treatments and lower values in T_1, T_4 and T_6 treatments than the initial EC value (0.98 millisiemens).

Improvement in soil fertility status was recorded when chemical fertilizers (75% NPK and 50% NPK) were integrated with organic manure and bio-fertilizers [23]. All the bio-fertilizer based treatments were significant in improving the organic carbon content over control except treatment T_2. The maximum content of organic carbon was observed in T_4 and T_5 treatments (0.38%) which were 22.58% more over control and fully chemical fertilizer based treatment.

The available nutrients in soil differed with different nutrient sources at the end of cropping season. A perusal of data presented in Table 4 entailed that the maximum available N in soil was recorded in T_2 treatment (184.95 kg ha^{-1}) where inorganic fertilizer was applied at 100% recommended dose. T_4 treatment (75% recommended dose of NP + 100% RDK + *Azotobacter chroococcum* @ 5 kg ha^{-1}) (183.29 kg ha^{-1}) exhibited similar trend and showed similarity with T_2. Available N status was 19.51%, 18.44% and 11.42% higher in T_2, T_4 and T_5 treatments, respectively, over control. The available P content was also highest (48.96 kg ha^{-1}) in T_2 (100% RDF), which was different from all other treatments; while the minimum value was obtained in control plots (38.37 kg ha^{-1}). On the other hand, while considering the availability of K in post-harvest soil, the T_4 treatment was superior (217.89 kg ha^{-1}) than any other treatments except T_2 (209.10 kg ha^{-1}) and the available K status was lowest (168.18 kg ha^{-1}) where no fertilizer was applied (T_1).

Table 1. Effect of inorganic and bio-fertilizer on N, P and K concentration in grain and straw of rice

Treatment	Concentration (%)					
	Grain			Straw		
	N	P	K	N	P	K
T_1	1.04	0.19	0.39	0.73	0.10	1.32
T_2	1.29	0.43	0.65	0.92	0.18	2.12
T_3	1.11	0.37	0.56	0.79	0.17	1.92
T_4	1.19	0.40	0.60	0.85	0.18	2.02
T_5	1.18	0.39	0.60	0.81	0.18	1.98
T_6	1.09	0.38	0.54	0.77	0.16	1.85
T_7	0.99	0.33	0.50	0.73	0.13	1.72
S.Em. (±)	0.02	0.01	0.01	0.02	0.01	0.02
CD (p=0.05)	0.08	0.03	0.04	0.05	0.02	0.06

T_1: control, T_2: chemical fertilizer at 100% recommended dose of NPK, T_3: 50 % recommended dose of NP + 100% RDK + Bacillus polymyxa, T_4: 75% recommended dose of NP + 100% RDK + Azotobacterchroococcum, T_5: 75% recommended dose of NP + 100% RDK + Bacillus polymyxa, T_6: 50% recommended dose of NP + 100% RDK + Pseudomonas fluorescence and T_7: 50 % recommended dose of NPK + Bacillus polymyxa

Table 2. Effect of inorganic and bio-fertilizer on nutrient uptake by grain and straw of rice

Treatment	Uptake (kg ha^{-1})					
	Grain			Straw		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1	49.02	8.83	18.45	42.74	5.69	77.61
T_2	72.74	24.47	36.67	64.06	12.60	147.98
T_3	59.05	19.86	29.80	51.41	11.01	124.28
T_4	65.21	21.78	32.74	59.10	12.72	140.26
T_5	63.55	20.91	32.28	53.79	12.18	131.23
T_6	55.82	19.65	27.83	48.23	10.04	116.34
T_7	49.77	16.44	24.74	44.89	7.95	105.49
S.Em. (±)	2.15	0.77	1.06	1.14	0.53	2.39
CD (p=0.05)	6.69	2.41	3.29	3.55	1.65	7.46

T_1: control, T_2: chemical fertilizer at 100% recommended dose of NPK, T_3: 50 % recommended dose of NP + 100% RDK + Bacillus polymyxa, T_4: 75% recommended dose of NP + 100% RDK + Azotobacterchroococcum, T_5: 75% recommended dose of NP + 100% RDK + Bacillus polymyxa, T_6: 50% recommended dose of NP + 100% RDK + Pseudomonas fluorescence and T_7: 50 % recommended dose of NPK + Bacillus polymyxa

Table 3. Effect of inorganic and bio-fertilizer on grain and straw yield as well as total nutrient uptake by rice

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Total N uptake (kg ha^{-1})	Total P_2O_5 uptake (kg ha^{-1})	Total K_2O uptake (kg ha^{-1})
T_1	4720	5880	91.76	14.52	96.05
T_2	5660	6990	136.80	37.07	184.65
T_3	5320	6480	110.47	30.88	154.08
T_4	5480	6930	124.31	34.50	173.00
T_5	5400	6620	117.34	33.09	163.51
T_6	5120	6290	104.05	29.69	144.18
T_7	4980	6120	94.66	24.40	130.23
S.Em. (±)	167.13	114.84	1.95	1.03	2.51
CD (p=0.05)	520.67	357.77	6.07	3.21	7.82

T_1: control, T_2: chemical fertilizer at 100% recommended dose of NPK, T_3: 50% recommended dose of NP + 100% RDK + Bacillus polymyxa, T_4: 75% recommended dose of NP + 100% RDK + Azotobacterchroococcum, T_5: 75% recommended dose of NP + 100% RDK + Bacillus polymyxa, T_6: 50% recommended dose of NP + 100% RDK + Pseudomonas fluorescence and T_7: 50% recommended dose of NPK + Bacillus polymyxa

Table 4. Effect of inorganic and bio-fertilizer on soil fertility status

Treatment	pH	Electrical conductivity (millisiemens)	Organic carbon (%)	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
T_1	7.24	0.79	0.31	154.75	38.37	168.18
T_2	7.24	1.01	0.31	184.95	48.96	209.10
T_3	7.33	1.05	0.37	167.82	40.14	189.75
T_4	7.35	0.98	0.38	183.29	44.31	217.89
T_5	7.53	1.01	0.38	172.43	41.46	195.82
T_6	7.43	0.94	0.36	163.80	41.03	179.46
T_7	7.33	1.08	0.35	162.42	39.53	184.92
S.Em. (±)	0.04	0.04	0.02	3.38	0.57	3.70
CD (p=0.05)	0.11	0.12	0.05	10.54	1.76	11.54

T_1: control, T_2: chemical fertilizer at 100% recommended dose of NPK, T_3: 50% recommended dose of NP + 100% RDK + Bacillus polymyxa, T_4: 75% recommended dose of NP + 100% RDK + Azotobacterchroococcum, T_5: 75% recommended dose of NP + 100% RDK + Bacillus polymyxa, T_6: 50% recommended dose of NP + 100% RDK + Pseudomonas fluorescence and T_7: 50 % recommended dose of NPK + Bacillus polymyxa

3.5 Nutrient/Fertilizer Use Efficiency

Partial factor productivity: The perusal of data in Table 5 revealed that the partial factor productivity for N was recorded maximum in treatment T_3 (177.33 kg grain kg^{-1} nutrient applied) (50% recommended dose of NP + 100% RDK + *Bacillus polymyxa* @ 5 kg ha^{-1}), at par with T_6 (170.67 kg grain kg^{-1} nutrient applied) (50% recommended dose of NP + 100% RDK + *Pseudomonas fluorescence* @ 5 kg.ha^{-1}). But T_4 treatment (75% recommended dose of NP + 100% RDK + *Azotobacter chroococcum* @ 5 kg ha^{-1}) showed the lowest PFP value (84.31 kg grain kg^{-1} nutrient applied). The highest PFP for P was noted in T_4 (243.56 kg grain kg^{-1} nutrient applied); which was different from all other treatments and the highest PFP for K was recorded in T_7 (332.00 kg grain kg^{-1} nutrient applied). The minimum values were observed in T_5 and T_6 treatments respectively.

Agronomic efficiency: The highest AE of N, P and K were observed in treatment T_3 (20.00 kg grain kg^{-1} N), T_4 (33.78 kg grain kg^{-1} P_2O_5) and T_2 (31.33 kg grain kg^{-1} K_2O). The lowest values were found in T_7 (8.67 kg grain kg^{-1} N), T_7 (7.43 kg grain kg^{-1} P_2O_5) and T_6 (13.33 kg grain kg^{-1} K_2O) treatments respectively.

Apparent recovery: A view of the Table 6 reveals that the apparent N, P and K recovery varied from 9.69% to 75.07%, 28.23% to 88.79% and 160.40% to 295.33%, respectively as influenced by different organic and inorganic combinations. Achievable level of recovery efficiency of N was registered in T_2 treatment (75.07%) over other treatments and it as on par with 50% recommended dose of NP + 100% RDK + *Bacillus polymyxa* @ 5 kg.ha^{-1} (T_3) (61.38%). The highest AR of P and K were registered in T_4 (88.79%) and T_2 (295.33%) treatments.

Physiological efficiency: The data showed that higher physiological efficiency of N (68.85 kg grain kg^{-1} N uptake) was obtained under T_7 (50% recommended dose of NPK + *Bacillus polymyxa* @ 5 kg ha^{-1}) and it was followed by T_3 treatment. Absolute control recorded no physiological efficiency due to absence of external fertilizer. The maximum values of PE of P and K (40.26 kg grain kg^{-1} P uptake and 10.82 kg grain kg^{-1} K uptake) were observed under T_2 and T_3 and the lowest efficiencies were found in T_6 (26.94 kg grain kg^{-1} P uptake) and T_7 (7.73 kg grain kg^{-1} K uptake) treatments respectively.

Table 5. Effect of inorganic and bio-fertilizer on partial factor productivity (PFP) and agronomic efficiency (AE) of rice

Treatment	PFP*			AE**		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1	-	-	-	-	-	-
T_2	94.33	188.67	188.67	15.67	31.33	31.33
T_3	177.33	152.00	177.33	20.00	17.14	20.00
T_4	84.31	243.56	182.67	11.69	33.78	25.33
T_5	120.00	127.06	180.00	15.11	15.99	22.67
T_6	170.67	146.28	170.67	13.33	11.43	13.33
T_7	165.99	142.29	332.00	8.67	7.43	17.33
S.Em. (±)	3.02	6.27	5.70	3.61	5.72	6.35
CD (p=0.05)	9.63	19.99	18.18	N/A	18.25	N/A

** Partial factor productivity (kg grain kg^{-1} nutrient applied)*
*** Agronomic efficiency (kg grain kg^{-1} nutrient applied)*

Table 6. Effect of inorganic and bio-fertilizer on apparent recovery (AR) and physiological efficiency (PE) of rice

Treatment	AR*			PE**		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1	-	-	-	-	-	-
T_2	75.07	75.17	295.33	20.37	40.26	10.44
T_3	61.38	46.74	193.41	33.62	36.13	10.82
T_4	50.09	88.79	256.49	23.55	38.09	9.83
T_5	56.85	43.69	224.85	27.44	38.03	10.21
T_6	40.98	43.36	160.40	27.78	26.94	7.90
T_7	9.69	28.23	227.84	68.85	27.01	7.73
S.Em. (±)	5.70	3.65	9.08	9.73	7.67	2.40
CD (p=0.05)	18.20	11.65	28.99	31.04	N/A	N/A

** Apparent recovery (%)*
*** Physiological efficiency (kg grain kg^{-1} nutrient uptake)*

Table 7. Effect of inorganic and bio-fertilizer on internal utilization efficiency (IUE) of rice

Treatment	IUE*		
	N	P_2O_5	K_2O
T_1	51.42	325.35	49.08
T_2	41.37	152.69	30.67
T_3	48.17	172.47	34.62
T_4	44.04	159.13	31.64
T_5	46.02	164.29	33.04
T_6	49.27	172.99	35.52
T_7	52.64	205.09	38.27
S.Em. (±)	1.22	3.80	0.93
CD (p=0.05)	3.81	11.84	2.90

** Internal utilization efficiency (kg grain kg^{-1} nutrient uptake)*

Internal utilization efficiency: The data further revealed that the highest IUE of N, P and K were recorded in treatment T_7 (52.64 kg grain kg^{-1} N uptake), T_1 (325.35 kg grain kg^{-1} P uptake) and T_1 (49.08 kg grain kg^{-1} K uptake) respectively. A very high IE suggests deficiency of that particular nutrient. The lowest IUE of N, P and K were registered in T_2 treatment (41.37, 152.69 and 30.67 kg grain kg^{-1} nutrient uptake respectively).

4. DISCUSSION

Increased N uptake due to increasing levels of chemical fertilizers may be ascribed to the fact that rice plants grew better and accumulated more dry matter in NPK treated plots leading to higher N uptake in comparison to control [24,25]. The results showed that the addition of organic amendments *i.e.* bio-fertilization had positive response on N uptake and it was high with the recommended dose of chemical fertilizer followed by combined application of bio-fertilizer along with inorganic fertilizer (T_4 and T_5).This might be due to (i) increased supply of all nutrients directly through organic and inorganic source to crop, (ii) indirectly through checking the losses of nutrient from soil solution and (iii) by increasing in the nutrient use efficiency. Higher N content (low C: N ratio) in inorganic fertilizer resulted in rapid decomposition and subsequently greater release of N during the crop growth period leading to higher N uptake by the crop as compared to bio-fertilizer based treatments. In addition to that it has priming effects that facilitates various biological transformations in soil. The N uptake by rice grain and straw were increased with the combined application of organic manure and chemical fertilizers [26]. Similar results were also reported by different scientists [27,28]. Enhancement in N uptake by rice plants with nutrient sources especially bio-fertilizers supplemented with any level of inorganic fertilizers probably resulted in the availability of more amount of nutrients throughout the plant growth as compared to sole application of fertilizers, indicating better utilization of applied nutrients under the combined application of inorganic and organic source of plant nutrients [29,30,31]. Phosphorus removal in rice grain was also found higher by about one and half times or even more than its uptake in straw, because of higher translocation efficacy of nutrient in grain (economic part) under integrated use of organic and inorganic nutrient sources [32]. Similar findings were reported by another scientist who described that nutrient content as well as nutrient uptake by rice over other treatments could be achieved due to combined application of organic and inorganic fertilizers [33]. Organic manures increased labile, moderately stable and stable organic P content in soil as well as uptake by plants [34]. These results inferred that a general increase in P uptake seemed to be associated with the P availability which happened due to the increasing levels of NPK application when soil is deficient in P. Besides this, the results revealed that the increase in nutrient supply obviously induced better plant growth which might have improved the absorption of phosphorus from the soil. The present findings are also in conformity with the several earlier reports which revealed enhanced P uptake by rice crop as a result of increased NPK supply [35,36]. Increase in K uptake with progressive increase in the supply of NPK nutrients in rice-rice cropping system was due to higher availability of these nutrients which ultimately resulted in higher biomass yield [37]. Thus, the results indicated that conjoint use of organic with the balanced levels of inorganic sources enhanced K uptake over control, in both the cases *i.e.* rice grain and straw. Satisfying the nutrient requirement of plants through combined application of inorganic fertilizer and bio-fertilizers was found equally promising in supplying nutrient elements in available form due to rapid release from chemical source as well as slow and steady release from bio-fertilizers in the soil along with micronutrients and growth promoting substances which resulted in higher growth and yield of crops. The low organic carbon content in soil was observed under inorganic fertilizer based treatment due to rapid mineralization and absence of formation of organo-mineral complexes [38]. Different bio-fertilizers have been demonstrated to act as valuable soil amendments that offer a balanced nutritional release pattern to plants, providing nutrients such as available N, soluble K, exchangeable Ca, Mg, and P that can be taken up readily by plants besides being a source of several micronutrients [39,40]. After incorporation of bio-fertilizer or inorganic sources of fertilizer, the mineralization process released adequate quantity of nutrients in the soil. In this experiment it was very clear that phosphate solubilising bacteria (PSB) *viz*. *Bacillus polymyxa* and *Pseudomonas fluorescens* played an important role to solubilise phosphate and made it available to rice plant. The PSB inoculation can effectively enhance P solubility of applied rock phosphate fertilizers, maintain a favourable soil P pool and increase productivity of aerobic rice and it was confirmed by [41]. The combined application of organic nutrient source and chemical fertilizer increased the organic matter content, available N, P_2O_5 and K_2O in the post-harvest soils. It could be due to enhanced nutrient pool at elevated fertility level which might have contributed to higher residual nutrient status of soil by retaining part of external applied nutrients in soil. Partial factor productivity (PFP) is a simple production efficiency expression, calculated in units of crop yield per unit of nutrient applied. It is easily calculated for any farm that keeps records of inputs and yields. However, PFP values vary among crops in different cropping systems, because crops differ in their nutrient and water needs. The increase in PFP was mainly due to reduced nutrient application according to crop demand, in turn reduces the losses of nutrient by various means. This was in accordance with two other eminent rice researchers [42,43]. No nutrient use efficiency was observed under absolute control. Similar results of lower efficiencies was observed due to more nutrient losses from soil-plant system leading to low NUE, when nutrient application is not synchronized with crop demand [44]. Agronomic efficiency (AE) is calculated in units of yield increase per unit of nutrient applied. It more closely reflects the direct production impact of an applied fertilizer and relates directly to economic return. The calculation of AE requires knowledge of yield without nutrient input, so is only known when research plots with zero nutrient input have been implemented on the farm. Apparent recovery (AR) is one of the more complex forms of NUE expressions and is most commonly defined as the difference in nutrient uptake in above-ground parts of the plant between the fertilized and unfertilized crop relative to the quantity of nutrient applied. It is often the preferred NUE expression by scientists studying the nutrient response of the crop. Increased level of AR depends on crop demand for nutrients, supply of nutrients from indigenous sources, fertilizer rate, timing and mode of application. Recovery efficiency depends on the congruence between plant demand and nutrient release from fertilizer and is affected by the application method (amount, timing, placement and N form) and factors that determine the size of the crop nutrient sink (genotype, climate, plant density, abiotic/biotic stresses). Physiological efficiency (PE) is defined as the yield increase in relation to the increase in crop uptake of the nutrient in above-ground parts of the plant. These results clearly showed that when fertilizer N is applied in right quantity and right time when crop can translate it effectively in to grain yield, higher fertilizer N use efficiency can be expected [45]. Internal utilization efficiency (IUE) is defined as the yield in relation to total nutrient uptake. It varies with genotype, environment and management. Low IE suggests poor internal nutrient conversion due to other stresses (deficiencies of other nutrients, drought stress, heat stress, mineral toxicities, pests etc.).

5. CONCLUSION

Based on the findings of the experiment, it was observed that the application of full dose of fertilizer through inorganic sources or their combination with bio-fertilizers resulted higher nutrient concentration in rice grain and straw, nutrient uptake and nutrient use efficiencies of rice as compared to control. It was clearly observed from the present study that the reduction of the dose of N and P of chemical fertilizer by 25% did not restrict the nutrient uptake and nutrient use efficiencies when it is substituted by the *Azotobacter chroococcum*. Therefore it can be concluded that combined application of bio-fertilizer and inorganic fertilizer *i.e.* treatment T_4 (75% recommended dose of NP + 100% RDK +*Azotobacter chroococcum*@ 5 kg ha^{-1}) and T_5 (75% recommended dose of NP + 100% RDK + *Bacillus polymyxa* @ 5 kg ha^{-1}) can be recommended for achieving higher rice yield in a cost effective manner and also for sustaining soil health and reducing environmental pollution.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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