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Research Paper

Contribution of microbial inoculation and zinc-fertilization to growth and yield of rice (*Oryza sativa*) under different cultivation methods in a sub-tropical and semi-arid type climate

A.A. SHAHANE[1], Y.S. SHIVAY[2], D. KUMAR[3] AND RADHA PRASANNA[4]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

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ABSTRACT

A field experiment was conducted at ICAR-Indian Agricultural Research Institute, New Delhi during rainy season of 2013–14 and 2014–15 in sandy clay loam soil to verify and validate the contribution of 2 microbial inoculations and zinc (Zn) fertilization on growth, yield and economics of rice (*Oryza sativa* L.). Rice variety 'Pusa Sugandh 5' was grown under 3 methods of cultivation, viz. puddled transplanted rice (PTR), system of rice intensification (SRI) and aerobic rice system (ARS) and 4 nutrient management options, viz. recommended dose of nutrients (RDN) ($N_{120}P_{25.8}$), 75% RDN, 75% RDN + *Anabaena sp.* (CR1) + *Providencia sp.* (PR3) and 75% RDN + *Anabaena- Pseudomonas* (An-Ps) biofilmed formulation with and without Zn (5 kg Zn/ha through $ZnSO_4.7H_2O$). Thus making total eight nutrient management options along with one absolute control ($N_0P_0Zn_0$). Results of 2 year study revealed that, microbial inoculation of An-Ps biofilmed formulation with 75% RDN increased number of tillers/m^2 by 16 and 13 with Zn and by 12 and 10 without Zn in first and second year, respectively. Increase in shoot dry matter due to CR1 + PR3 consortia with 75% RDN was 40.6 and 36.3 g/m^2 with and without Zn in first and 31.4 and 28.6 g/m^2 with and without Zn in second year, respectively. Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing grain yield was 0.29 and 0.30 t/ha with and without Zn and same for CR1 + PR3 consortia was 0.28 and 0.30 t/ha with and without Zn, respectively. Aerobic method saved 6,000 and 9,640 ₹/ha as compared to PTR, while SRI saved 3,440 and 5,800 ₹/ha as compared to PTR in first and second year, respectively. Contribution of microbial inoculation of An-Ps biofilmed formulation in increasing net returns was 7,500 and 7,670 ₹/ha with and without Zn and same for CR1 + PR3 consortia was 7,350 and 7,660 ₹/ha with and without Zn, respectively.

Key words **:** Aerobic rice system, Biological nitrogen fixation, Rice, System of rice intensification, Zinc fertilization

Rice is dietary and protein currency of Indian and world populations as it provide staple food of more than 50% of the world's population and supplies 20 and 31% of total calories required by world and the Indian population, respectively (Zeigler and Barclay, 2008). Any variation in input resources and output from rice paddies has impact on large population. Even in era of diversification of crop and human diet, rice till date play a pivotal place in human dietary intake. As rice grain shaped the cultures, diets and economies of billions of people in the world and in India, its complete replacement was difficult to: i) avoid losses of resources in rice production system like water and nutrient, ii) avoid adverse impact of rice production system on environment like greenhouse gas emission and degrading inherent soil resources and iii) to improve nutrient fact such as Zn in human diet. In such situation diversifying rice cultivation methods from puddled transplanted rice (PTR) to system of rice intensification (SRI) and aerobic rice system (ARS) is one among other possible options. Along with cultivation methods, diversification in nutrient sources also helps producer in several ways if the sources are economically viable and ecologically sustainable. Use of microbial inoculations containing biological nitrogen fixation (BNF) systems and phosphorus solubilising bacteria (PSB) in combination with chemical fertilizer need to

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[1]**Corresponding author's Email:** amitiari89@gmail.com

[1]Ph.D. Scholar, [2]Professor and Principal Scientist, [3]Principal Scientist, Division of Agronomy, [4]Principal Scientist, Division of Microbiology, ICAR-Indian Agricultural Research Institute, New Delhi 110 012

be objectively assessed in crop production. Along with major nutrients, fertilization of rice crop with Zn has positive impact on rice yield (Shivay *et al*., 2015) and also improves Zn content in rice grain which helps in alleviating Zn deficiency, which rank fifth among the most important health risk factor in developing countries and eleventh globally (Palmgren *et al*., 2008). With this background, the present study was conducted to verify and validate contribution of 3 resource diversification techniques on rice growth and yield, viz. contribution of less water requiring ARS and SRI to rice yield in comparison to PTR, contribution of BNF and PSB to rice yield and contribution of Zn fertilization to rice yield.

MATERIALS AND METHODS

A field experiment was conducted during rainy season for 2 consecutive years (2013–14 and 2014-15) on the Research Farm of ICAR-Indian Agricultural Research Institute, New Delhi located at 28°38' N, 77°10' E, 228.6 m above the mean sea-level. The climate of Delhi is of subtropical and semi-arid type with hot and dry summer and cold winter and falls under the agro-climatic zone 'Trans-Gangetic plains'. The mean annual normal rainfall is 650 mm, with July and August as the wettest months and annual mean pan evaporation of about 850 mm. Weather condition prevailing during both rice growing seasons were different. Total rainfall received in first and second year during rice growing season was 1,349.8 mm and 451.4 mm, which was higher by 699.8 mm in first year and lower by 198.6 mm in second year than mean annual normal rainfall (650 mm). Evaporation losses during first and second rice growing season were 806 mm and 1075.1 mm respectively. This indicates that weather condition was not much favourable for growth and development of rice in second year of experiment. The soil of experimental field was sandy clay loam in texture having *p*H 7.6, organic carbon 0.54% and available N, P, K and DTPA-extractable Zn of 257 kg/ha, 17 kg/ha, 327 kg/ha and 0.85 mg/kg, respectively.

The experiment involving rice variety 'Pusa Sugandh 5' was executed in split-plot design comprised of 3 main-plots as a methods of rice cultivation, viz. Puddled transplanted rice (PTR), System of rice intensification (SRI) and Aerobic rice system (ARS) with 9 nutrient management options as sub-plot treatments. Sub-plot treatments consisted of four treatments, viz. recommended dose of nutrients (RDN) ($N_{120}P_{25.8}$), 75% RDN, 75% RDN + *Anabaena sp.* (CR1) + *Providencia sp.* (PR3) and 75% RDN + *Anabaena-Pseudomonas* (An-Ps) biofilmed formulation with and without Zn, thus making total 8 treatments along with 1 absolute control ($N_0P_0Zn_0$). Potassium (K) was applied uniformly at the rate of 49.8 kg K/ha as basal dose. In case of Zn soil application of 5 kg Zn/ha through Zn sulphate heptahydrate was applied in both rice crops. Sowing of rice in main field for ARS and sowing rice in nursery for transplanting in both PTR and SRI was done on same date. For ARS, direct sowing of seed (seed rate 60 kg/ha) was done with spacing of 20 cm between 2 rows using seed-drill. In SRI, 1 healthy seedling of 14-days old were transplanted/hill at a spacing of 20 cm × 20 cm, whereas in PTR, 2 healthy seeding of 25-days old, were transplanted/hill at a spacing of 20 cm × 15 cm. For application of microbial inoculants, a thick paste of respective culture was made and applied to rice seedling in PTR and SRI method of rice cultivation by dipping roots in paste of respective culture for half an hour before transplanting. In direct seeded rice pre-soaked seeds were treated with thick paste of culture made in carboxyl methyl cellulose. Nitrogen was split applied in all treatments irrespective of dose at sowing, 30 days after sowing (DAS) and 60 DAS in ARS and 5 days after transplanting (DAT), 25 DAT and 55 DAT in both PTR and SRI. In case of P, K and Zn all dose as per treatment details was applied at the time of sowing/transplanting. For weed management hand weeding was done twice (20 and 40 DAT) in PTR and SRI and thrice (15, 30 and 45 DAS) in ARS and use of herbicide was avoided on the ground of adverse impact on inoculated microbial population. Irrigation was given to maintain soil water level at field capacity in ARS and in SRI irrigation was applied to maintain saturated field condition. In PTR, 5 cm depth of water was applied in each irrigation after complete disappearance of water.

Plant tillers were counted from randomly selected one meter square area from each plot at harvest. For measurement of above ground shoot dry matter air dried plant samples were further dried in a hot air oven at $60^{o}\pm2^{o}C$ temperature till constant weight was obtained and expressed in g/m^2. Rice panicle characteristics and yield attributes were measured from a sample of 10 panicles drawn at random from each plot at harvesting. The net plots were harvested and sun-dried in the field and then weighed to record the total biomass yield. Rice grain yield was measured after cleaning and drying. Weighing of the grain was done at 14% moisture content, while straw yield was calculated by subtracting grain yield from the total biomass yield. Zinc (Zn) concentration in rice were determined as per the procedure described by Prasad *et al*. (2006) using Atomic Absorption Spectrophotometer (AAS) and uptake was computed by multiplying Zn concentration with grain and straw yields. Gross and net returns were calculated based on grain and straw yields and their prevailing market prices and benefit: cost ratio was calculated by dividing net returns by cost of cultivation. All the data obtained from the experiment were statistically analysed using the F-test as per the standard statistical procedure (Gomez and Gomez, 1984) and least significant difference (LSD) values (P = 0.05) were used to determine the significance of difference between treatment means.

RESULTS AND DISCUSSION

Biometric parameters

Effective tillers/m^2 in SRI (346/m^2 and 321/m^2) was statistically superior to PTR in both years even though plant population in SRI was lower than PTR (Table 1). Tillers in PTR were significantly higher than ARS and ARS stand statistically inferior to both PTR and SRI in both years. Significantly lower number of effective tillers/m^2 was reported (Hugar *et al*., 2009) in aerobic method than SRI. Tillers were higher in first year with the highest variation between first and second year in control (59 tillers/m^2), while variation in rest of treatments were 18–22 tillers/m^2. This indicates that adverse impacts of high temperature during establishment and low rainfall on growth of rice were more on control and adequate fertilization of rice able to reduce this impact. Among nutrient management options, the highest tillers/m^2 were recorded in RDN + Zn which were remained on a par with 75% RDN+ An-Ps biofilmed formulation + Zn and 75% RDN + CR1+ PR3 + Zn. These 3 treatments recorded significantly higher tillers/m^2 than same treatments without Zn application, which indicates that Zn fertilization had positive effect on tillers/m^2. The contribution of Zn fertilization was the highest with 75% RDN + CR1 + PR3 + Zn (9.7 and 8.2 tillers/m^2 in first and second year, respectively) and the lowest in RDN + Zn (8.6 and 6.9 tillers/m^2 in first and second year respectively). Increase in tillers/m^2 due to Zn fertilization was also observed by Shivay *et al*. (2015).

Shoot dry matter accumulation also followed similar trend as that of the tillers/m^2 in all 3 cultivation methods and nutrient management options. SRI had significantly higher dry matter than both PTR and ARS. Dry matter in PTR was statistically superior to ARS. Significantly higher dry matter in both mechanical and manual transplanting than direct dry seeded rice was reported in study conducted by Singh *et al*. (2005). Among years, first year recorded higher dry matter than second year. Variation between years was the highest in control (120 g/m^2) and in rest treatments it was 108 to 112 g/m^2. Contribution of microbial inoculation of An-Ps biofilmed formulation to dry-matter production was 41.2 and 32.0 g/m^2 with and without Zn in first and 36.6 and 30.1 g/m^2 with and without Zn in second year and same for CR1 + PR3 consortia was 40.6 and 36.3 g/m^2 with and without Zn in first and 31.4 and 28.6 g/m^2 with and without Zn in second year. Lower contribution during second year in both inoculations indicates that, performance of applied inoculations lower in adverse weather condition prevailing in second year of experiment. Performance of both microbial inoculations was better with Zn fertilization during both years as mentioned-above. A significant enhancement in plant biomass was also recorded (Prasanna *et al*., 2012) in treatments involving combined inoculation with bacterial and cyanobacterial strains in pot experiments.

Yield attributing characters

Panicle length, filled spikelets, weight/panicle, filled spikelets/panicle and spikelet fertility percentage (%) in SRI and PTR was significantly higher than ARS in the both years (Table 1). Higher numbers of panicles/hill and grains/panicle in SRI method was reported in Wahlang *et al*. (2015); while significantly lower spikelets/panicle in ARS compared to PTR was also mentioned Mallareddy and Padmaja (2013). Unfilled grains were significantly lower in both PTR and SRI than ARS. Among nutrient management options, RDN + Zn recorded the highest value for panicle length, filled grains weight/panicle, filled spikelets/panicle and fertility percentage, which remained on a par with 2 treatments, viz. 75% RDN + An-Ps biofilmed formulation + Zn and 75% RDN + CR1 + PR3 + Zn. These three treatments stand statistically superior to all other treatments in yield attributes as discussed above. Unfilled spikelets were significantly lower in above-mentioned 3 treatments than rest of nutrient management options.

Contribution of SRI and PTR to increase filled spikelets weight/panicle was 0.30 g and 0.25 g/panicle in first year and 0.26 g and 0.22 g/panicle in second year as compared to ARS, respectively. The contribution of Zn fertilization to filled spikelets weight/panicle was the highest in RDN + Zn (0.36 g and 0.22 g/panicle in first and second year respectively) and the lowest in 75% RDN + Zn (0.14 g and 0.13 g/panicle in first and second year, respectively). Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing filled spikelets weight/panicle was 0.40 and 0.36 g/panicle with and without Zn in first year and 0.31 and 0.50 g/panicle with and without Zn in second year and same for CR1 + PR3 consortia was 0.35 and 0.33 g/panicle with and without Zn in first year and 0.28 and 0.27 g/panicle with and without Zn in second year. Increase in panicle weight due to application of different combination of PR3 and PR7 (both *Providencia sp.*), CR1, CR2 and CR3 (*Anabaena sp.*) was also recorded by Prasanna *et al.* (2012). Contribution of SRI method to increase the filled spikelets was 1.4 and 1.5 spikelets/panicle than PTR in first and second year respectively and 9.9 and 10 spikelets/panicle than ARS in first and second year respectively.

Table 1. Influence of cultivation methods and nutrient management options on biometric parameters and yield attributes of rice

Treatment	Effective tillers/m²		Shoot dry-matter accumulation at 100 DAS (g/m²)		Panicle length (cm)		Filled spikelets weight/panicle (g)		Filled spikelets/panicle		Unfilled spikelets/panicle		Fertility percentage (%)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Methods of cultivation														
Puddled transplanted rice	342.9	318.0	705.9	593.6	27.4	25.7	2.71	2.48	125.6	115.0	36.1	34.0	77.4	76.8
System of rice intensification	346.0	321.4	711.2	598.2	27.7	25.9	2.76	2.52	127.0	116.5	35.7	33.9	77.9	77.2
Aerobic rice system	334.6	310.3	691.3	581.3	25.7	23.9	2.46	2.26	117.1	106.5	38.6	36.8	74.9	74.0
SEm±	0.69	0.72	1.35	1.18	0.17	0.08	0.030	0.022	0.73	0.59	0.22	0.20	0.19	0.16
CD (P=0.05)	2.69	2.84	5.29	4.62	0.68	0.30	0.118	0.087	2.87	2.31	0.86	0.80	0.75	0.63
Nutrient management options														
Control ($N_0P_0Zn_0$)	282.1	222.3	592.9	472.9	19.8	17.8	1.94	1.62	94.2	81.7	44.3	42.4	67.9	65.7
RDN ($N_{120}P_{25.8}$)	349.5	328.8	718.2	606.5	27.9	26.2	2.64	2.50	128.3	118.4	35.6	33.7	78.2	77.8
RDN + Zn (5 kg Zn/ha)	358.1	335.7	738.0	626.4	29.7	27.8	3.00	2.72	138.6	123.1	32.8	31.1	80.8	79.8
75% RDN ($N_{90}P_{19.35}$)	334.7	316.4	683.1	575.6	25.1	23.1	2.41	2.18	110.1	101.2	39.9	37.7	73.4	72.8
75% RDN + Zn	340.2	321.7	693.8	585.1	26.3	24.9	2.55	2.31	116.8	109.1	38.0	36.2	75.4	75.1
75% RDN + CR1 + PR3	346.3	326.6	714.5	604.3	27.4	25.7	2.69	2.45	124.8	117.9	36.4	34.7	77.4	77.2
75% RDN + CR1 + PR3 + Zn	356.0	334.8	734.4	621.4	29.2	27.4	2.90	2.64	135.0	122.3	33.8	32.1	79.9	79.2
75% RDN + An-Ps biofilmed formulation	347.0	327.1	715.1	605.7	27.6	25.7	2.72	2.68	125.7	118.0	36.5	34.4	77.4	77.4
75% RDN + An-Ps biofilmed formulation + Zn	356.3	335.2	735.0	621.7	29.3	27.5	2.95	2.67	135.5	122.5	33.7	31.8	80.0	79.4
SEm±	1.85	1.68	3.58	3.09	0.32	0.20	0.044	0.041	1.34	1.29	0.44	0.41	0.33	0.35
CD (P=0.05)	5.27	4.79	10.18	8.79	0.90	0.58	0.124	0.116	3.81	3.67	1.24	1.16	0.95	1.01

RDN, recommended dose of nitrogen; 120 kg/ha and phosphorus, 25.8 kg P/ha; Zn, soil applied 5 kg Zn/ha through zinc sulphate heptahydrate

The contribution of Zn fertilization to filled spikelets/panicle was the highest in RDN + Zn (10.3 and 4.7 filled spikelets/panicle in first and second year, respectively) and the lowest in 75% RDN + Zn (6.7 and 7.9 filled spikelets/panicle in first and second year, respectively). This indicates that, optimum dose of N and P is needed to achieve better response of Zn application. Contribution of Zn fertilization to increasing spikelets/ panicle was also reported by Shivay *et al.* (2015). Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing filled spikelet was 18.7 and 15.2 numbers of filled spikelets/ panicle with and without Zn in first year and 13.4 and 16.8 numbers of filled spikelets/panicle with and without Zn in second year and same for CR1 + PR3 consortia was 18.2 and 14 numbers of filled spikelets/panicle with and without Zn in first year and 13.2 and 16 numbers of filled spikelets/panicle with and without Zn in second year. Contribution of both microbial inculcations was higher in first year than second year which indicates that inculcation did not perform well in second year having low rainfall and higher evaporative demand due to intense high temperature.

Grain, straw and biological yields

Grain, straw and biological yields were the highest in SRI method, which remained on a par with PTR and both these methods stand superior to ARS (Table 2). Statistically identical grain yield in SRI and PTR was reported by Chapagain *et al.* (2011), while in another study Hugar *et al.*, (2009) found that higher grain yield in SRI than ARS. Among nutrient management options, the highest yield was recorded in RDN + Zn, which were statistically identical with 2 treatments, viz. 75% RDN + An-Ps biofilmed formulation + Zn and 75% RDN + CR1 + PR3 + Zn. These 3 treatments were found statistically superior than rest of the treatments in both year. Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing grain yield was 0.29 and 0.30 t/ ha with and without Zn in first year and 0.33 and 0.21 t/ha with and without Zn in second year and same for CR1 + PR3 consortia was 0.28 and 0.30 t/ha with and without Zn in first year and 0.33 and 0.19 t/ha with and without Zn in second year. Improvement in yield due to application of CR2, CR1 (both *Anabaena* sp.) and PR10 (*Ochrobacterium* sp.) with two-third nitrogen was also recorded in Prasanna *et al.* (2012). The contribution of Zn fertilization to increasing grain yield was 0.14 and 0.22 t/ha in first and second year, respectively with RDN, while contribution with 75% RDN was 0.17 and 0.08 t/ha in first and second year respectively. Contribution of Zn to increase grain yield with 75% RDN + CR1+ PR3 was 0.15 and 0.22 t/ha and with 75% RDN + An-Ps biofilmed formulation was 0.16 and 0.20 t/ha in first and second year respectively. Increase in grain yield due to Zn fertilization was also reported by Shivay *et al.* (2015).

Economics

Cost of cultivation: Contribution of ARS for saving of cultivation cost was 6,000 and 9,640 ₹/ha in first and second year as compared to PTR, while contribution of SRI to saving of cultivation cost was 3,440 and 5,800 ₹/ha as compared to PTR (Table 2). Lower cost of cultivation in dry direct seeding of rice than transplanted rice was also observed in a study conducted by Singh *et al.* (2005). Contribution of microbial inoculation to saving of cultivation cost was 190 and 200 ₹/ha in first and second year, respectively. Though saving in cultivation cost was less, yield improvement due to microbial inoculation increased gross returns and ultimately reflected in net returns. Application of Zn increase cost of cultivation by 830 ₹/ha in all Zn applied treatment as rate, source and method of application was same in all treatments.

Gross and net returns and benefit: cost ratio:

Gross returns in PTR and SRI were the higher than ARS by 4,160 and 4,170 ₹/ha in first year and 4,540 and 4,540 ₹/ha in second year respectively, which was mainly due to higher yield in both PTR and SRI methods (Table 2). Contribution of Zn fertilization to increase in gross returns with 75% RDN + CR1 + PR3 was 4,100 and 6,090 ₹/ha and with 75% RDN + An-Ps biofilmed formulation was 4,240 and 5,540 ₹/ha in first and second year respectively, which was higher than extra cost of Zn application (830 ₹/ha). Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing gross returns was 7,690 and 7,860 ₹/ha with and without Zn in first year and 9,140 and 5,830 ₹/ha with and without Zn in second year and same for CR1 + PR3 consortia was 7,540 and 7,850 ₹/ha with and without Zn in first and 9,140 and 5,280 ₹/ha with and without

Table 2. Influence of cultivation method and nutrient management options on yield, returns and zinc uptake of rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Gross returns (× 10^3 ₹/ha)		Net returns (× 10^3 ₹/ha)		Benefit: cost ratio		Cost of cultivation (× 10^3 ₹/ha)		Total Zn uptake (g/ha)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Methods of cultivation														
Puddled transplanted rice	4.08	3.95	7.30	7.07	112.5	109.0	66.0	53.0	1.42	0.95	46.51	55.96	474.2	445.9
System of rice intensification	4.10	3.97	7.30	7.08	112.8	109.4	69.8	56.8	1.62	1.08	43.07	52.51	477.2	449.9
Aerobic rice system	3.93	3.80	7.02	6.79	108.3	104.8	67.6	58.5	1.66	1.26	43.43	46.32	429.3	400.3
SEm±	0.016	0.010	0.025	0.017	0.34	0.281	0.34	0.28	0.008	0.005	-	-	3.34	1.64
CD (P=0.05)	0.061	0.040	0.099	0.069	1.33	1.104	1.33	1.10	0.031	0.021	-	-	13.10	6.46
Nutrient management options														
Control ($N_0P_0Zn_0$)	3.28	3.10	6.35	5.96	91.4	86.3	50.5	37.3	1.25	0.77	40.84	48.97	340.4	304.1
RDN ($N_{120}P_{25.8}$)	4.16	4.00	7.34	7.09	114.4	110.1	70.7	58.3	1.62	1.13	43.70	51.87	478.6	449.7
RDN + Zn (5 kg Zn/ha)	4.30	4.22	7.52	7.50	118.1	116.2	73.6	63.5	1.66	1.22	44.53	52.7	511.3	493.3
75% RDN ($N_{90}P_{19.35}$)	3.82	3.76	6.96	6.64	105.5	103.5	62.4	52.2	1.45	1.03	43.09	51.26	417.9	386.6
75% RDN + Zn	3.99	3.84	7.13	6.79	109.9	105.7	66.0	53.6	1.51	1.04	43.92	52.09	443.3	409.3
75% RDN + CR1 + PR3	4.12	3.95	7.29	7.00	113.3	108.8	70.0	57.3	1.62	1.12	43.28	51.46	467.2	438.1
75% RDN + CR1 + PR3 + Zn	4.27	4.17	7.47	7.41	117.4	114.8	73.3	62.6	1.67	1.21	44.11	52.29	502.7	483.2
75% RDN + An-Ps biofilmed formulation	4.12	3.97	7.30	7.03	113.3	109.3	70.1	57.8	1.62	1.13	43.28	51.49	471.2	440.5
75% RDN + An-Ps biofilmed formulation + Zn	4.28	4.17	7.50	7.41	117.6	114.8	73.5	62.6	1.67	1.21	44.11	52.29	509.7	483.7
SEm±	0.031	0.021	0.042	0.037	0.705	0.590	0.70	0.59	0.016	0.011	-	-	4.09	2.71
CD (P=0.05)	0.088	0.061	0.121	0.106	2.004	1.677	2.00	1.67	0.045	0.031	-	-	11.62	7.70

RDN, Recommended dose of nitrogen 120 kg/ha and phosphorus 25.8 kg P/ha; Zn, soil applied 5 kg Zn/ha through zinc sulphate heptahydrate

Zn in second year, respectively.

Net returns were significantly higher in SRI as compared to ARS due to higher yield in SRI, while net returns in ARS were significantly higher than PTR due to lower cost of cultivation in ARS during first year. In second year of study, ARS recorded significantly higher net returns than SRI and both ARS and SRI stand superior to PTR due to lower cost of cultivation in both ARS and SRI. Higher net returns in SRI over PTR were also reported in Jat *et al.* (2015). Among nutrient management options, contribution of Zn fertilization to increase in net returns with 75% RDN + CR1 + PR3 consortia was 3,270 and 5,260 ₹/ha and with 75% RDN + An-Ps biofilmed formulation was 3,410 and 4,710 ₹/ha in first and second year respectively. The benefit: cost ratio in both years was significantly higher in ARS as compared to both SRI and PTR. Among nutrient management options, both Zn fertilization and microbial inoculation contributed significantly to increase in benefit: cost ratio. Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing benefit: cost ratio was 0.16 and 0.17 with and without Zn in first year and 0.17 and 0.10 with and without Zn in second year and same for CR1 + PR3 consortia was 0.16 and 0.17 with and without Zn in first and 0.17 and 0.09 with and without Zn in second year.

Zinc uptake

Total Zn uptake of rice was significantly higher in SRI and PTR than ARS in both years. Total Zn uptake in SRI was 47.9 and 49.6 g/ha higher than ARS, while in PTR it was 44.9 and 45.6 g/ha higher than ARS in first and second year, respectively. The highest uptake of Zn was recorded in RDN + Zn which remained on a par with 75% RDN + An-Ps biofilmed formulation + Zn and 75% RDN + CR1 + PR3 + Zn. These 3 treatments recorded significantly higher uptake than same treatment without Zn application. Increase in Zn uptake due to Zn fertilization was also recorded by Shivay *et al*. (2015). Contribution of Zn fertilization to improving uptake was the highest in 75% RDN + An-Ps biofilmed formulation + Zn (38.5 and 43.2 g/ha in first and second year respectively) and it was the lowest in 75% RDN (25.4 and 22.7 g/ha in first and second year respectively). This indicates the importance of Zn fertilization and importance of optimum fertilization of nitrogen and phosphorus in improving Zn uptake.

From the data presented above and discussion it can be concluded that, Zn fertilization and microbial inculcation contributed significantly to growth and yield of rice. The study verified that contribution of Zn fertilization and microbial inoculation to rice growth and yield was also reflected in gross and net returns of rice in both years. Involvement of An-Ps biofilmed formulation or CR1 + PR3 consortia with 75% RDN found a valid nutrient management option for rice. SRI method gave similar yield and higher net returns and hence can be adopted in place of PTR. Aerobic method even though gave lower yield, net returns was higher than PTR in both years and can be a valid option in low resource condition.

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