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ARTICLE

Assessment of different methods of rice (*Oryza sativa*. L) cultivation affecting growth parameters, soil chemical, biological, and microbiological properties, water saving, and grain yield in rice–rice system

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Abstract Field experiments were conducted at DRR farm located at ICRISAT, Patancheru, in sandy clay loam soils during four seasons, Kharif 2008, Rabi 2008–2009, Kharif 2009 and Rabi 2009–2010, to investigate growth parameters, water-saving potential, root characteristics, chemical, biological, and microbial properties of rhizosphere soil, and grain yield of rice (*Oryza sativa* L.) by comparing the plants grown with system of rice intensification (SRI) methods, with organic or organic + inorganic fertilization, against current recommended best management practices (BMP). All the growth parameters including plant height, effective tillers (10–45 %), panicle length, dry matter, root dry weight (24–57 %), and root volume (10–66 %) were found to be significantly higher with in SRI-organic + inorganic over BMP. With SRI-organic fertilization, growth parameters showed inconsistent results; however, root dry weight (3–77 %) and root volume (31–162 %) were found significantly superior compared to BMP. Grain yield was found significantly higher in SRI-organic + inorganic (12–23 and 4–35 % in the Kharif and Rabi seasons, respectively), while with SRI-organic management, yield was found higher (4–34 %) only in the Rabi seasons compared to BMP. An average of 31 and 37 % of irrigation water were saved during Kharif and Rabi seasons, respectively, with both SRI methods of rice cultivation compared to BMP. Further, total nitrogen, organic carbon%, soil dehydrogenase, microbial biomass carbon, total bacteria, fungi, and actinomycetes were found higher in the two SRI plots in comparison to BMP. It is concluded that SRI practices create favorable conditions for beneficial soil microbes to prosper, save irrigation water, and increase grain yield.

Keywords Methods of rice cultivation · System of rice intensification (SRI) · Microbial characteristics · Root characteristics · Irrigation water

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Introduction

Rice is the principal staple food for 65 % of the population of India. The demand for rice is expected to rise due to increase in population (1.6 % year^{-1}), while the area under rice cultivation is expected to reduce to 40 million ha in the next 15–20 years (Shobarani et al. 2010). Hence, there is a need to increase the yield and productivity of rice cultivation using reduced inputs and resources to feed the burgeoning population. System of rice intensification (popularly known as SRI), an alternative methodology for traditional flooded rice cultivation developed in the 1980s in Madagascar (Laulanié 1993), offers some instructive insights into "positive plant microbial interactions." SRI has been promoted for more than a decade as a set of agronomic management practices for rice cultivation that enhances yield (Kabir and Uphoff 2007; Namara et al. 2008; Senthilkumar et al. 2008) while reducing water requirements (Satyanarayana et al. 2007). The agronomic changes in SRI rice cultivation include the use of much younger seedlings than are normally transplanted, planting them singly and carefully in a square pattern with wide spacing in soil that is kept moist, but not continuously flooded and with increased amendments of organic matter and active aeration of the soil during weed control operation preferably with a mechanical weeder. SRI was also found more accessible to small land holders (Stoop et al. 2002) and is more favorable for the environment than conventional transplanting with its continuous flooding and heavy reliance on inorganic fertilization (Uphoff 2003).

Information on effects of organic nutrient application for rice under SRI and its comparison with best management practices (BMP) with regard to soil biological activity and the productivity of rice in Indian soils is still limited. Also, not much information is available on the effects of irrigation under SRI and BMP with regard to water saving and yield. The present experiments were conducted to investigate growth parameters, root characteristics, yield attributes, soil microbial activities, and water-saving potential by comparing the plants grown with different methods of rice cultivation (SRI-organic, SRI-organic + inorganic and BMP).

Materials and methods

Description of study area

Experiments were conducted at the Directorate of Rice Research (DRR) research farm, ICRISAT, Patancheru, Hyderabad, India (17°.53′N latitude, 78°.27′E longitude, 545 m altitude, with mean maximum and minimum temperatures of 32 and 20 °C, respectively, and mean annual precipitation of 750 mm), during Kharif (wet season) 2008, Rabi (dry season) 2008–2009, Kharif 2009 and Rabi 2009–2010 on an integrated rice ecosystem in an undisturbed field layout with permanent bunds around each plot. All the plots were surrounded by 1.5-m wide bunds to prevent lateral water seepage and nutrient diffusion between plots. Soils at the experimental site are classified as sandy clay loam, alkaline (pH 8.5–9.4), non-saline (EC 0.32 dS m^{-1}), and contained 1.01 % organic carbon, 795 ppm total N, 58 ppm available phosphorus (Olsen), and 190 ppm available potassium. The mean minimum and maximum temperatures, rainfall, and evaporation loss during the crop seasons (2008–2010) for Kharif and Rabi seasons are presented in Table 1.

Table 1 Weather parameters recorded during experimental period

Parameter	2008–2009		2009–2010	
	Kharif	Rabi	Kharif	Rabi
Minimum temperature (°C)	13–26	9–27	14–25	8–29
Maximum temperature (°C)	23–36	23–42	26–35	25–42
Rainfall (mm)	767	60	805	79
Evaporation (mm)	626	1,245	652	1,168

Experimental design and cultural practices

The experiment was laid out in a completely randomized block design with a plot size of 105 m^2 for each treatment. The three methods of crop establishment (SRI-organic, SRI-organic + inorganic and BMP) were the main treatments done with three replications each. The rice variety Sampada with bold grain quality which matures normally in 135 days, was tested during both Kharif and Rabi seasons. In SRI-organic + inorganic and BMP treatments, the inputs applied were the same (50 organic + 50 % inorganic), while in SRI-organic, the total nutrients were supplied through organic sources such as farm yard manure, vermicompost, and green manure (*Gliricidia sepium*, a leguminous N_2-fixing tree). The recommended doses of inorganic fertilizers were given at the rate of 100–60–40 kg N_2, P_2O_5, and K_2O ha^{-1} during Kharif season and 120–60–40–20 kg N_2, P_2O_5, K_2O, and Zn ha^{-1} during Rabi season through urea, single super phosphate, muriate of potash, and zinc sulfate, respectively. Nitrogen was given in three equal splits at basal, maximum tillering, and panicle initiation stages, while P, K, and Zn were given as basal doses. For SRI-organic treatments, the N dose was adjusted to the recommended level based on the moisture content and total N concentration of the organic sources. The average nutrient content of the organic fertilizers that were applied are shown in Table 2.

Nurseries were established adjacent to the experimental field so that transplanting could be performed rapidly to minimize seedling injury. In the SRI plots (both organic and inorganic), 10–12-day-old seedlings were transplanted, while 30-day-old seedlings were transplanted for BMP. BMP plots were kept flooded whenever required to maintain a layer of 5–6-cm depth of water during the vegetative stage. SRI plots were kept saturated, but with no standing water during the vegetative stage. After panicle initiation, both SRI and BMP plots were maintained with 2–3-cm depth of water and all the plots were drained 15 days before harvest. Weeding in SRI plots (both organic and inorganic) was done four times by cono-weeder to incorporate weeds into the soil at 10, 20, 30, and 40 days after transplanting (DAT), while the BMP plots were hand-weeded twice at 25 and 40 DAT.

Table 2 Average nutrient content of organic fertilizers

Organic source[a]	N (% N)	P (% P_2O_5)	K (% K_2O)
Compost	1.4	1.8	2.2
Gliricidia	2.4	0.1	1.8
Rice-straw	0.8	0.2	1.8

N nitrogen, *P* phosphorous, *K* potassium

[a] Organic fertilizers incorporated 1 week before transplanting rice

All the plants in an area of 5 × 5 m for each replicate (25 m^2) were harvested (excluding border rows) for determination of yield per unit area, and the grain yield was adjusted to 14.5 % seed moisture content. The harvest index was calculated by dividing dry grain yield with the total dry matter of above ground parts. Plant height, effective tiller number, panicle length, grain weight, and dry matter were determined from the crop harvested from a square meter area from each replication.

Root studies

Roots samples were collected from the top 15 cm of soil profile in all four seasons. The dug out soil was placed in big buckets, made into a slurry with excess water, and passed through a 2-mm sieve to collect roots and other debris, and was then stored in plastic bags. The root samples were brought to the lab, washed, and cleaned to remove debris. The root samples were analyzed for root volume (EPSON Expression 1640 XL, Japan) and dry weight (dried at 70 °C for 48 h).

Irrigation water use efficiency

Each plot was demarcated with a plastic lining to prevent seepage and was irrigated through pipes with digital water meters individually to account for total water applied. The water received through rainfall was uniform for all the treatments.

Chemical, biological, and microbiological properties of the rhizosphere soil from SRI and BMP

From each plot, three spots were selected from which three subsamples were collected and pooled, so that each field sample was a pool of three subsamples from three spots. The soil samples were each collected from 0- to 15-cm rhizosphere soil profile at harvesting using a 40-mm diameter soil core. One part of the pooled sample was air-dried under shade, pounded to break up large clods, sieved (<2 mm), and analyzed for three soil chemical parameters, viz., total N, available P, and % organic C as per the protocols of Novozamsky et al. (1983), Olsen and Sommers (1982) and Nelson and Sommers (1982), respectively. Another part of the pooled sample was transferred into polythene bags, stored in an ice-cold thermocol box and transported to the laboratory. These bags were stored in a refrigerator at 4 °C until analyzed for two soil biological activity indicators, dehydrogenase, and microbial biomass carbon (MBC) as per the protocols of Casida (1977) and Anderson and Domsch (1989), respectively, and for three microbiological variables (populations of total bacteria, actinomycetes, and fungi). Appropriate dilutions of the soil samples were plated on Luria agar for bacteria, actinomycetes isolation agar for actinomycetes and potato dextrose agar (PDA) with streptomycin @ 500 mg L^{-1} for fungi. The plates were incubated at 30 ± 2 °C for 24–120 h. The colonies with desired traits on different media were counted and recorded. The data were transformed into log units and expressed as colony-forming units (CFU) $\log_{10}$ g^{-1} dry soil. Moisture in the different soil samples was determined and the counts were converted to $gram^{-1}$ dry soil.

Statistical analysis

All the data were statistically analyzed by analysis of variance (ANOVA) as applicable to a completely randomized block design (Gomez and Gomez 1984). The significance of the treatment effect was determined by *F* tests, and to determine the significance of the difference between the means of the treatments, least significant difference (LSD) was calculated at the 5 % probability level.

Results and discussion

Growth parameters

In the present investigation, the seeds for both SRI and BMP plots were sown at the same time; however, the seedlings were planted into the main field at different times, 10–12-day-old seedlings for SRI, while 30-day-old seedlings were transplanted for BMP. The purpose for doing this was to have the plants under both treatments reaching similar stages of growth and receiving similar sunshine hours, day length and temperatures, for better comparison of the treatments.

Growth parameters including, effective tillers (m^{-2}), panicles length (cm), dry matter (t ha^{-1}), root dry weight (mg $plant^{-1}$), and root volume (cm^3 $plant^{-1}$) were found to be significantly higher in SRI-organic + inorganic treatments over BMP (Table 3). Among the growth parameters, effective tillers (10–45 %), root dry weight (24–57 %), and root volume (10–66 %) were found to be significantly higher over BMP in all four test seasons (Table 3). In the case of SRI-organic treatments, growth parameters showed inconsistent results; however, root dry weight and root volume were found superior (3–72 and 31–162 %, respectively) to BMP in all four test seasons (Table 3). Tillering ability (panicle bearing tillers) in rice has a close relationship with the number of phyllochrons completed before entering the reproductive stage (Stoop et al. 2002; Thakur et al. 2009). In the SRI method of rice cultivation, individual plants with more favorable growing conditions have shorter phyllochrons, which results in their having more productive tillers and larger root systems (Katayama 1951; Thakur et al. 2009). Rice plants grown under standing water, as in the case of BMP, encounter hypoxic (anoxic) soil conditions and about three-fourths of their roots are degenerated by the flowering stage (Kar et al. 1974). Further, transplanting of young seedlings, as in SRI methods, has the tendency to improve root characteristics such as root length, density and root weight compared with older seedlings, as used in BMP (Mishra and Salokhe 2008). Other studies have also reported that SRI plants have deeper root systems and larger roots compared to those conventionally grown in flooded rice systems (Satyanarayana et al. 2007; Tao et al. 2002). In the present investigation, the root systems were found to be significantly healthier with both SRI-organic + inorganic and SRI-organic treatments (Table 3). Hence, it can be confirmed that SRI methods of rice cultivation support better root growth over BMP.

Yield parameters

Grain yield was found to be significantly higher in SRI-organic + inorganic (12–23 and 4–35 % more in Kharif and Rabi seasons, respectively) compared to BMP in all four tested seasons, while in the SRI-organic treatment, yield was found to be higher (4–34 %) only in the Rabi seasons (Table 4). The mean grain yield ranged between 3.39 and 8.12 t ha^{-1} for SRI-organic, and 5.24 and 8.17 t ha^{-1} for SRI-organic + inorganic as compared to 4.29–6.05 t ha^{-1} in BMP (Table 4). Rice straw yield at harvest was also found to be greater compared to BMP in all SRI-organic + inorganic treatments except in Kharif 2008 and only in the Rabi 2009–2010 trials with SRI-organic treatments (Table 4). Harvest Index was also found to be greater in both SRI-organic (except Kharif 2009) and SRI-organic + inorganic (except Rabi 2008–2009) treatments over BMP (Table 4). The divergence in grain yield between SRI and BMP was more attributable to differences in Harvest Index than to dry matter production.

In the present investigation, it was also observed that the plants grown in SRI had more open architecture, with wider spread of tillers, covering more ground area and more erect leaves (data not shown) that avoided mutual shading of leaves (Thakur et al. 2010). With higher light interception, this would lead to more photosynthesis and higher grain yield in SRI compared to BMP. Sakamoto et al. (2006) also observed similar observation that erect

Table 3 Comparison of growth parameters as influenced by SRI-organic, SRI-organic + inorganic, and best management practices (BMP)

Season	Treatment	Growth parameters						
		Plant height (cm)	Effective tillers (m^{-2})	Panicle length (cm)	Grain weight (g)	Dry matter (t ha^{-1})	Root dry weight (mg plant^{-1})	Root volume (cm^3 plant^{-1})
Kharif season (2008)	SRI-org	65	221	21.2	20.6	7.97	1,226	52
	SRI-org + inorg	74	373	22.8	21.8	12.3	1,334	55
	BMP	73	256	21.4	21.3	11.84	1,075	39
	LSD (0.05 %)	1	53	1.1	2.6	1.60	146	8
Kharif season (2009)	SRI-org	57	312	17.7	18.2	8.18	1,070	63
	SRI-org + inorg	58	528	20.2	18.7	10.11	1,570	40
	BMP	57	480	19.5	17.5	8.87	1,040	24
	LSD (0.05 %)	5.3	50	1.9	1.8	2.01	220	18
Rabi season (2008–2009)	SRI-org	74	307	21.1	14.3	9.94	1,314	53
	SRI-org + inorg	76	444	21.6	14.9	11.51	1,203	46
	BMP	72	370	20.6	14.0	10.62	764	36
	LSD (0.05 %)	6	57	1.4	0.7	1.71	104	NS
Rabi season (2009–2010)	SRI-org	81	449	21.2	14.6	15.62	2,657	63
	SRI-org + inorg	86	425	22.5	14.8	15.27	2,546	53
	BMP	75	356	22.5	14.7	12.15	2,025	48
	LSD (0.05 %)	6.5	70	1.4	2.2	1.92	131	10

Org organic, *inorg* inorganic, *LSD* least significant difference, *NS* non-significant

Table 4 Comparison of water inputs with grain yield, straw yield, and harvest index (HI) as influenced by SRI-organic, SRI-organic + inorganic, and best management practices (BMP)

Season	Treatment	Water parameters				Yield parameters		
		Water input (m^3 ha)	Water productivity (kg grain m^3)	Liters of water kg^{-1} grain	% water saved over BMP	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	HI (%)
Kharif (2008)	SRI-org	5885.2	0.576	2,462	44.9	3.39	4.58	42.53
	SRI-org + inorg	7167.9	0.731	1,368	32.9	5.24	7.06	42.60
	BMP	10680.1	0.439	2,270		4.69	7.15	39.61
	LSD (0.05 %)	734.0				0.57	1.08	1.74
Kharif season (2009)	SRI-org	11466.2	0.323	4,247	29.2	3.70	4.48	45.23
	SRI-org + inorg	13365.9	0.395	2,531	17.5	5.28	4.83	52.23
	BMP	16200.9	0.265	3,776		4.29	4.58	48.37
	LSD (0.05 %)	1031.0				0.27	0.62	3.88
Rabi season (2008–2009)	SRI-org	7730.6	0.707	1,414	47.1	5.45	4.49	54.83
	SRI-org + inorg	8268.0	0.658	1,520	43.2	5.44	6.07	47.26
	BMP	14562.0	0.360	2,779		5.24	5.38	49.34
	LSD (0.05 %)	1326.0				NS	0.8	4.19
Rabi season (2009–2010)	SRI-org	10254.8	0.792	1,263	32.4	8.12	7.5	51.98
	SRI-org + inorg	11125.3	0.734	1,362	26.7	8.17	7.1	53.50
	BMP	15168.1	0.399	2,507		6.05	6.1	49.79
	LSD (0.05 %)	1328.0				0.63	1.2	2.87

Org organic, *inorg* inorganic, *LSD* least significant difference

leaves in rice increased both biomass production and grain yield. A number of previously published reports on SRI have shown enhancement in rice yield (Namara et al. 2008; Satyanarayana et al. 2007; Sato and Uphoff 2007; Thakur et al. 2009).

In the present investigation, grain yield was found higher in Rabi seasons compared to Kharif seasons probably due to bright sunshine and favorable weather for the crop and less pest and disease attack. Seshu and Cady (1984) reported 30 % higher radiation during the Rabi season over Kharif season on the rice crop which correlated positively with the economic yield. This increase could be attributed to soils during Rabi being less saturated (less hypoxic), favoring larger concentrations of more beneficial aerobic soil organisms in the rhizosphere.

The grain yield in SRI-organic + inorganic was found consistently and significantly higher in all four tested seasons, whereas it was found higher only in two seasons (both Rabi) in SRI organic over BMP. One of the possible reasons for the lower yield in SRI-organic compared to SRI-organic + inorganic trials could be the slower and gradual release of nutrients from the organic fertilizers which might not be sufficient to meet the requirements of the crop. Repeated applications of organics over several years are often required to buildup sufficient soil fertility especially where inorganic fertilization has been applied, affecting soil biota. Significant reduction in rice yield was reported by Yadav et al. (2000) when 50 % chemical fertilizers were substituted with organics. The recession in crop yields during an initial phase of transition from conventional to organic agriculture and recovery in the yields after 2–3 years was reported by Sharma and Singh (2004). This dynamic is probably dependent on multiple soil factors, needing more extensive and systematic evaluation over time. Even four seasons may not be sufficient to evaluate these effects, especially if plots are assigned treatments randomly as in standard scientific methodology.

Irrigation water use efficiency

Irrigation water inputs for different methods of rice cultivation were recorded using digital water meters during the four crop seasons. They indicated water savings with SRI management up to 17–47 % (Table 4). Both the SRI-organic and SRI-organic + inorganic received significantly lower irrigation water compared to BMP in all the four seasons (Table 4). Irrigation water savings averaged 31 and 37 % during Kharif and Rabi seasons, respectively, in both SRI methods of rice cultivation over BMP (Table 4). Further, irrigation water use efficiency (WUE) was found to be higher in SRI-organic compared to SRI-organic + inorganic treatments (Table 4). Similar observations were found in the literature where 25–50 % of irrigation water was reported to be saved in SRI over conventional method of rice cultivation (Chapagain and Yamaji 2010; Randriamiharisoa and Uphoff 2002; Thiyagarajan et al. 2002). Kunimitsu (2006) reported that the economic value of irrigation water for paddy fields ranges from 0.4 to 0.65 US$/$m^3$, depending on the location of paddy field. In this study, when the cost of irrigation water saved was calculated, as per the calculations of Kunimitsu (2006), it was found that monetary savings were US$ 2,340–2,700 and US$ 1,380–1,740 ha^{-1} during Kharif and Rabi seasons of 2008 and 2009, respectively. Further, the quantity of water required for generating one kilogram of rice was found to be 1,263–1,414 and 1,362–1,520 L of water in SRI-organic and SRI-organic + inorganic treatments, respectively, compared to 2,507–2,779 L of water in BMP in the Rabi seasons (Table 4). Thus, physical water requirements for the production were about 40–50 % lower, leading to the conclusion that with the SRI methods, irrigation use efficiency is higher than with conventional methods of rice cultivation.

Chemical, biological, and microbiological properties of the rhizosphere soil from SRI and BMP

Total N and OC% were found to be significantly higher in both SRI-organic and SRI-inorganic treatments over BMP in all the seasons analyzed; however, for SRI-organic treatments, samples of total N were not analyzed in Kharif 2008 nor were total N, total P, and OC% in Rabi 2008–2009 (Table 5). Samples of total N were also not analyzed for SRI-inorganic and BMP treatments in Kharif 2008. In the last two seasons (Kharif 2009 and Rabi 2009–2010), total N and OC% were found to be significantly higher in SRI-organic (16–22 and 12–20 %, respectively) and SRI-organic + inorganic (3–13 and 5–10 %, respectively) treatments over BMP (Table 5). Not much difference in total P was observed, however, in either SRI-organic or SRI-organic + inorganic treatments compared to BMP (Table 5). Soil dehydrogenase and microbial biomass carbon (MBC) were also found to be significantly higher in SRI-organic (11–18 and 34–38 %, respectively) and SRI-organic + inorganic (9–50 and 6–34 %, respectively) treatments over BMP in all four seasons (except in Rabi 2008–2009 and Rabi 2009–2010 for which samples from SRI-organic treatments were not analyzed) (Table 5). The microbial populations (total bacteria, fungi, and actinomycetes) were found to be always higher in SRI-organic and SRI-organic + inorganic treatments over BMP (except in Rabi 2008–2009 for which the organic treatments were not analyzed) (Table 6). It should be noted, however, that the approach of quantifying microbial population through plate-count techniques estimate only <10 % of the total microflora in the soil (Nannipieri et al. 1994). Therefore,

Table 5 Comparison of soil biological activity and nutrient status as influenced by SRI-organic, SRI-organic + inorganic, and best management practices (BMP)

Season	Treatment	Dehydrogenase (μg TPF g^{-1} soil 24 h^{-1})	MBC (μg g^{-1} soil)	Total N (ppm)	Total P (ppm)	OC %
Kharif season (2008)	SRI-org	188.0	672.0	*	108.0	1.14
	SRI-ore + inore	186.0	643.0	*	96.0	1.15
	BMP	170.0	500.0	*	93.0	1.13
	LSD (5 %)	13.6	120.7		12.5	0.02
Kharif season (2009)	SRI-org	97.0	623.0	1674.0	94.0	1.38
	SRI-org + inorg	110.0	605.0	1549.0	91.0	1.27
	BMP	82.0	450.0	1375.0	91.0	1.15
	LSD (5 %)	14.8	151.0	73.2	3.0	0.01
Rabi season (2008–2009)	SRI-org	*	*	*	*	*
	SRI-org + inorg	326.0	1218.0	1103.0	134.0	1.20
	BMP	267.0	1153.0	1083.0	130.0	1.19
	LSD (5 %)	26.2	19.5	2.6	1.8	0.02
Rabi season (2009–2010)	SRI-org	*	*	1497.0	122.0	1.25
	SRI-org + inorg	274.0	781.0	1328.0	122.0	1.17
	BMP	183.0	706.0	1287.0	120.0	1.12
	LSD (5 %)	89.5	4.3	206.6	2.4	0.07

MBC microbial biomass carbon, *N* nitrogen, *P* phosphorous, *OC* organic carbon, *ppm* parts per million, *org* organic, *inorg* inorganic, * not analyzed, *LSD* least significant difference

Table 6 Comparison of microbial population as influenced by SRI-organic, SRI-organic + inorganic, and best management practices (BMP)

Years	Treatment	Total bacteria	Total actinomycetes	Total fungi
Kharif season (2008)	SRI-org	5.79	4.60	5.59
	SRI-org + inorg	5.79	4.66	5.71
	BMP	5.77	4.41	5.42
	LSD (5 %)	0.01	0.11	0.10
Kharif season (2009)	SRI-org	5.97	5.00	3.81
	SRI-org + inorg	6.08	4.90	3.81
	BMP	5.80	4.73	3.78
	LSD (5 %)	0.08	0.20	0.02
Rabi season (2008–2009)	SRI-org	*	*	*
	SRI-org + inorg	6.94	5.56	5.72
	BMP	6.81	5.52	5.59
	LSD (5 %)	0.16	0.10	0.13
Rabi season (2009–2010)	SRI-org	6.88	6.04	4.88
	SRI-org + inorg	6.76	5.84	4.99
	BMP	6.76	5.69	4.68
	LSD (5 %)	0.01	0.13	0.04

Org organic, *inorg* inorganic, * not analyzed, *LSD* least significant difference, Microbial populations were expressed in Log_{10} values

molecular quantification (more reliable method) needs to be done in future studies.

Application of organic fertilizers, as done in SRI-organic and SRI-organic + inorganic treatments where more organic fertilizers were applied compared to BMP, has been reported to enhance the population of indigenous bacteria (Lal et al. 2000). Superior soil fertility status (N, P, K, and OC%) on organic farms compared to soils fertilized with chemical fertilizers has been reported by Sharma and Singh (2004) and Singh et al. (2004). Enhanced microbial activity in organically managed soil increases rates of carbon and nitrogen mineralization and also soluble carbon content (Sharma and Singh 2004). Higher microbial diversity and soil biological activity in the form of microbial biomass C and N, respiration, and dehydrogenase activity have been reported with organic additions (Carpenter-Boggs et al. 2000; Liebig and Doran 1999; Rao 2005). The enzyme dehydrogenase is regarded as an indicator of total life in the soil and a strong indicator of biological activity. The enhancement of soil chemical, biological, and microbiological properties in SRI-organic and SRI-organic + inorganic treatments over BMP could be due to their different water management (saturation vs. flooding) and weed management methods (use of mechanical weeder which incorporates weeds and aerates the soil vs hand weeding which just removes weeds). The presence of more microbial and biological activity in the rhizosphere leads to beneficial functions for crops such as plant growth promotion, nitrogen fixation, phosphate solubilization, induced systemic resistance and protection against pathogens.

Conclusion

In the present investigation, growth parameters including effective tillers, panicle length, dry matter, root dry weight, and root volume were found to be significantly higher in SRI-organic + inorganic trials, whereas with SRI-organic treatments, only root dry weight and root volume were found to be significantly higher compared to BMP. Grain yield was found significantly higher in SRI-organic + inorganic (4–35 %) in both Kharif and Rabi seasons, while with the SRI-organic, the yield was found to be higher (4–34 %) only in the Rabi seasons. An average of 31–37 % of irrigation water was saved during the respective crop seasons with both SRI methods of rice cultivation over BMP. Further, soil chemical, biological, and microbiological activities were also found to be higher in both sets of SRI plots over BMP. This is clear evidence that SRI management is not only a seed-saving method but also a water-saving technology. The water saved for rice can be effectively used for increasing the area under rice or other irrigated dry crops in the cropping sequence, thereby enhancing the system productivity. It can be concluded that SRI practices create conditions for beneficial soil microbes to prosper, for saving irrigation water and for increasing grain yield. The role of soil microbes in enhancing rice plant productivity, even affecting the expression of genetic potentials, is just beginning to be studied (Chi et al. 2005, 2010). Further, long-term research studies at different locations are useful to quantify each component of SRI, for enhancing resource conservation, wide scale adoptability, and molecular assessment of microbial populations in the soil and the effects of symbiotic endophytes to assess positive soil–plant–microbial interactions.

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