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Influence of different methods of rice (*oryza sativa* l.) cultivation on microbes, soil health, water productivity and grain yield

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Abstract

The System of Rice Intensification (SRI) developed in Madagascar, a systems approach to increasing rice productivity with less reliance on exogenous inputs, is gaining attention all over the world including India. Indian Institute of Rice Research conducted a multi-year experiment (2008-09 to 2010-11) to compare the effects of different nutrient amendments (organic and/or inorganic) used with either SRI methods or with recommended best management practices (BMP) for growing puddled rice on sandy clay loam soils to study the effects on rice water productivity, soil health and microbes functioning were assessed. With integrated nutrient management combining organic and inorganic nutrient applications(INM) in SRI method yielded higher mean grain yield than BMP in both wet season (15.7%) and dry season (22.8%). The superior performance of SRI was associated with higher microbial biomass carbon (MBC) and with higher levels of dehydrogenase activity an indicator of biological presence and activity in the soil. Respectively and collectively, SRI practices (young seedlings, wide spacing, active soil aeration through inter-cultivation with mechanical weeder, water management that saturates the soil but does not inundate it, and enhancement of soil organic matter) create more aerobic soil conditions under which beneficial microbes and other soil organisms can prosper and improve the soil‘s structure and fertility. Water productivity of SRI method is higher (0.41 to 0.73 kg grain/m^3) in kharif (0.65 to 0.97 kg grain/m^3) in rabi over best management practice (0.26 to 0.62 kg grain/m^3).

Keywords: System of Rice Intensification (SRI), grain yield, water productivity, soil health, microbial activity

Introduction

Rice, the principal staple food for two-thirds of India‘s population, is cultivated on 42 million ha, thereby producing 106 m tonnes in 2015-16. The demand for rice in India is expected to continue rising due to annual increase in population (1.6%), with declining arable land area per capita and with higher costs and/or less availability of inputs such as water. The System of Rice Intensification (SRI) has been promoted for more than a decade as a set of agronomic management practices for rice cultivation that enhances crop yield and reduces water requirements (Satyanarayana *et al.*, 2007; Senthil Kumar *et al.*, 2008) [16, 17]. SRI has also been found to be more accessible for small landholders as it is not dependent on purchased inputs (Stoop *et al.*, 2002) [19], and it is more benign for the environment than conventional production methods with their continuous flooding of rice paddies and heavy reliance on inorganic fertilisation and biocides (Uphoff, 2003; Uphoff and Dazzo 2016) [24, 5]. Increased and indiscriminate use of chemical fertilizers and pesticides since the onset of the Green Revolution during 1970s has resulted in a number of harmful effects on soil, water and air. This has reduced the productivity of soil systems by diminishing soil fertility and biological activity over time, creating need or incentive to further increase their use. Remarkable progress has been made over the past 50 years in agricultural production and food self-sufficiency in many countries, including India, with such input-dependent strategy. But these gains have been attained at some cost to soil health and potentially human health. Unbalanced nutrient management and decreases in soil. organic matter are key factors responsible for this decline. Levels of soil organic carbon usually range between 0.1% and 1% in India (Manna *et al.*, 2003) [9]. This puts a premium on finding ways to reduce the use of chemical inputs and to improve their use efficiency. Making assessments of alternative crop management strategies is complicated by the fact that microbial-based indicators of soil quality are more difficult to measure and are generally more dynamic than those of the soil’s physical and chemical properties. Such assessments need to be undertaken, however, as best they can be made. Microbial communities are important determinants of the soil‘s organic matter decomposition rates, and this affects the turnover and availability of nutrients in agricultural soils. Microbial soil characteristics are attaining increased interest as indicators of soil health because of the relationships between microbial diversity, soil and plant quality, and ecosystem sustainability. Although grain yield under organic farming is often lower than under conventional farming, at least initially, it is feasible to have increased rice yields under the former. This has been the widespread experience with SRI crop management (Uphoff, 2016) [25]. Information on organic rice farming under SRI methods and comparison with best management practices (BMP) for rice-growing to see their effects on soil biological activity and on productivity in Indian soils and climate is rather scanty. The experiment reported here was conducted to investigate soil microbial populations, water productivity and grain yield by comparing the plants grown with different methods of crop establishment (SRI–organic, and SRI-INM) vs. best management practices (BMP-INM) maintaining flooded paddies during the growth cycle.

Material and methods

The studies were conducted at the experimental farm of the Indian Institute of Rice Research which is located at the International Center for Research in the Semi-Arid Tropics (ICRISAT) near Hyderabad (17°53'N latitude; 78°27'E longitude; 545 m altitude) for three consecutive wet (*kharif*) and dry (*rabi*) seasons, 2008-09 to 2010-11, to investigate the effects on grain yield of different practices.The mean minimum and maximum temperatures of 12- 36 ^{0}C in kharif with mean rainfall of 851 while 4.5 ^{0} C – 42 ^{0}C of min amd maximum temperature respectiviely with 49 mm of lower rainfal during dry (rabi) season (Table.1).

Table 1: Weather parameters recorded during experimental period

Parameter	2008−09		2009−10		2010−11	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Minimum temperature (°C)	13−26	9−27	14−25	8−29	12-24.2	4.5 -27.2
Maximum temperature (°C)	23−36	23−42	26−35	25−42	21.8-34.5	25.2-40.4
Rainfall (mm)	767	60	805	79	981	8
Evaporation (mm)	626	1245	652	1168	557	926

Rice plants grown with different crop establishment methods and different forms of fertilization were compared: SRI practices with organic nutrient supplementation only; SRI with integrated nutrient management (INM), a combination of organic and inorganic sources; and transplanted rice with best management practices (BMP) and INM (organic + inorganic fertilization). Soils at the experimental site, classified as sandy clay loam, are alkaline (pH 8.5−9.4) and non-saline (EC 0.32 dS m^{-1}), and they contain 1.01% organic carbon, 795 ppm total N, 58 ppm available phosphorus (Olsen and Sommers, 1982) [13], and 190 ppm available potassium. Trials were managed during the six seasons in a field lay-out with the plots (105 m^{-2}) for each treatment having permanent bunds (1.5 m wide) around them to prevent lateral water seepage and nutrient diffusion between plots.

The three methods of crop establishment (SRI-organic, SRI-INM, and BMP) were the main treatments done with three replications each. The same rice variety *Sampada*, with bold grain quality and maturing normally in 135 days, was tested during both wet and dry seasons. In the SRI-INM and BMP treatments, the inputs applied were the same (50% organic + 50% inorganic), while in the SRI-organic treatments, 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 fertilizer were given with a ratio of 100−60−40 for N_2, P_2O_5 and K_2O ha^{-1} during wet season, and 120−60−40−20 kg N_2, P_2O_5, K_2O and Zn ha^{-1} during rabi season. These were provided through urea, single super phosphate, muriate of potash, and zinc sulphate, 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 just before planting. 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. Standard management methods for SRI and BMP were used as shown in Table 2.

Table 2: Crop management practices followed in SRI and best management practices (BMP) plots

Practices	SRI (both organic and inorganic)	BMP
Nursery	5 kg seed ha^{-1}, in an area of 100 m^2; broadcasted on a raised bed and irrigated with rose can 3−4 times a day	30 kg seed ha^{-1} in an area of 1000 m^2 and grown in flooded situation
Seedling age	10−12-day-old	30-day-old
Plant spacing	One seedling per hill at a spacing of 25 x 25 cm (square planting)	Three seedlings per hill at a spacing of 20 × 15 cm
Weed management	Weeding with cono-weeder, performed at 10, 20, 30 and 40 DAT	Hand and manual weeding performed at 25 and 40 DAT, respectively
Water management	Seedlings transplanted at 1−2 cm puddled saturated field without any standing water. During the vegetative stage, plots were kept saturated (not flooded) and after panicle initiation 2−3 cm of standing water was maintained and drained 15 days before the harvest	Seedlings transplanted at 2−5 cm puddled field with 5−6 cm pounded water and same level was maintained during the vegetative stage. After panicle initiation 2−3 cm of standing water was maintained and drained 15 days before the harvest

The average nutrient content of the organic fertilizers that were applied is shown in Table 3.

Table 3: Average nutrient content of organic fertilizers

Organic nutrient sources*	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

*Organic fertilizers were incorporated one week before transplanting rice; N = nitrogen; P = phosphorous; K = potassium

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

The soil samples were collected from 0 to 15 cm rhizosphere soil profile at harvesting using a 40 mm diameter soil core. From each plot, three spots were selected from which again three subsamples were collected and pooled. Each field sample was a pool of three subsamples from three spots and pooled. 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) [12], Olsen and Sommers (1982) [13] and Nelson and Sommers (1982) [11], respectively. Another part of the pooled sample was transferred into polythene bags, stored in an ice-cold thermocol box and transported to the laboratory analysed for two soil biological activity indicators (dehydrogenase and microbial biomass carbon [MBC] as per the protocols of Casida [1977] [2] and Anderson and Domsch [1989] [1], respectively) and three microbiological analyses (population 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±2ºC for 24 to 72 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) log10 g-1 dry soil. Moisture in the different soil samples was determined, and the counts were converted to per gram dry soil.

Statistical analysis

All the data were statistically analyzed using analysis of variance (ANOVA) as applicable to a completely randomized block design (Gomez and Gomez 1984). The significance of the treatment effect was determined using F-Test, 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

Grain yield

Grain yield was found to be significantly higher in SRI-INM treatments (12−23% and 4−35% more in the kharif and rabi seasons, respectively) compared to BMP in all six tested seasons, while with the SRI-organic treatment, yield was higher than BMP (by 4−34%) only in the rabi seasons. The mean grain yield ranged between 3.4 and 9.4 t ha^{-1} for SRI-organic, and 5.2 and 10.7 t ha^{-1} for SRI-INM as compared to 4.3–8.5 t ha^{-1} in BMP (Table 4 and Fig. 1). The divergence in grain yield between SRI and BMP was attributable more to differences in the Harvest Index than to dry matter production.

Table 4: Grain yield of SRI vs. BMP as influenced by nutrient management in different seasons

Treatments	Grain yield (t/ha)							
	Kharif				Rabi			
	2008	2009	2010	Mean	2008	2009	2010	Mean
SRI-Organic	3.39	3.70	5.29	4.12	5.45	8.12	9.37	7.65
SRI-INM	5.24	5.28	5.65	5.39	5.44	8.17	10.67	8.09
BMP	4.69	4.29	4.99	4.66	5.24	6.05	8.47	6.59
LSD (0.05%)	0.57	0.67	0.7	0.65	NS	0.63	0.35	0.49
Mean				4.72				7.44

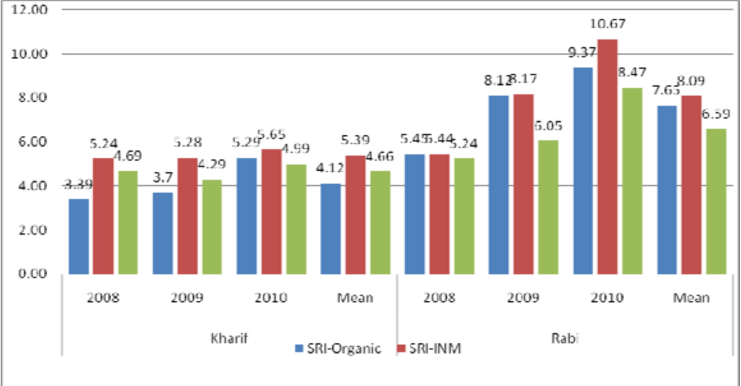

Fig.1 Trends of Grain yield as influenced by methods in different seasons and years

In our investigation, it was observed that the plants grown in SRI had a more open architecture, with wider spread of tillers covering more ground area, and more erect leaves which avoided the mutual shading of leaves. With higher light interception, this would lead to more photosynthesis and higher grain yield in SRI plants compared to BMP. A number of previously published reports on SRI have shown enhancement in rice yield with these methods (Sato and Uphoff, 2007; Thakur *et al*., 2010) [16, 20]. In the present investigation, grain yield was found to be 57% higher in rabi seasons compared to kharif seasons, probably due to brighter sunshine and more favorable weather for crop growth and also less pest and disease attack. Seshu and Cady (1984) [18] reported that the 30% higher radiation during the rabi season over kharif season on the rice crop correlated positively with economic yield. This increase could also be attributed in part to the soils during rabi being less saturated (less hypoxic), which would favor larger concentrations of more beneficial aerobic soil organisms in the rhizosphere.

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

Total N and levels of organic carbon (%OC) in the soil were found to be significantly higher than BMP in the SRI-organic treatments (by 16−22% and 12−20%, respectively) and SRI-INM treatments (by 3−13% and 5−10%, respectively) (Fig.2). However, not much difference in total P was observed in either the SRI-organic or SRI-INM treatments compared to BMP. Levels of soil dehydrogenase and microbial biomass carbon (MBC) were also found to be significantly higher in the SRI-organic (11−18% and 34−38%, respectively) and SRI-INM treatments (9−50% and 6−34%, respectively) treatments over BMP across all three seasons.

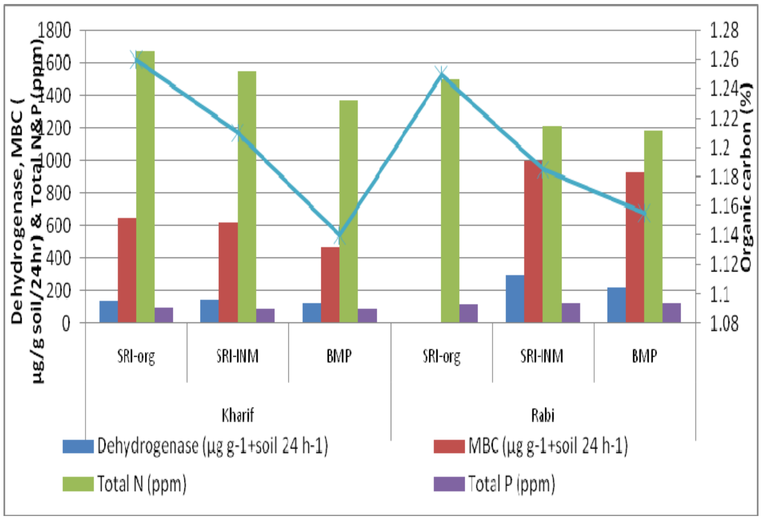

Fig 2: Comparisons of soil biological activity and nutrient levels as influenced by methods of crop establishment and seasons

MBC – microbial biomass carbon; N = nitrogen; P = phosphorous; OC = organic carbon; ppm = parts per million; org = organic; INM = organic + inorganic; * = not analyzed; LSD = least significant difference

The microbial populations (total bacteria, fungi and actinomycetes) were found to be always higher in SRI-organic and SRI-INM as compared to BMP (Table 5). It should be noted, however, that the approach of quantifying microbial population through plate-count techniques estimates probably less than 10% of the total microflora in the soil (Nannipieri *et al.* 1994) [10]. Therefore, molecular quantification (a more reliable method) needs to be done in future studies.

Table 5: Comparisons of microbial populations as influenced by

Season	Treatment	Total Baceria	Total actinomycetes	Total Fungi	Total organisms
Kharif -Wet	SRI-org	5.880	4.800	4.700	15.380
	SRI-INM	5.935	4.780	4.760	15.475
	BMP	5.785	4.570	4.600	14.955
	Mean	5.867	4.717	4.687	15.270
Rabi- Dry	SRI-org	6.880	6.040	4.880	17.800
	SRI-INM	6.850	5.700	5.355	17.905
	BMP	6.785	5.605	5.135	17.525
	Mean	6.838	5.782	5.123	17.743

org = organic; INM = organic + inorganic;
Microbial populations are expressed in Log_{10} values

The count of total organisms ranged from 15.38 to 15.47 during kharif, 17.80 to 17.90 during rabi over BMP (14.95 to 17.52 log 10 values during kharif and rabi respectively).

Irrigation water use efficiency

Irrigation water inputs for different methods of rice cultivation were recorded using digital water meters during both crop seasons indicated that the water saving in SRI could be up to 17−52% (Fig. 3; Table 6). Both the SRI-organic and SRI-organic + inorganic received significantly lower irrigation water compared to BMP. An average of 28% and 43% of irrigation water were saved during Kharif and Rabi seasons, respectively, in both SRI methods of rice cultivation over BMP. Further, the irrigation water use efficiency was found higher in SRI-organic compared to SRI-INM treatments. 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; Chowdhury *et al*. 2005; Randriamiharisoa and Uphoff 2002; Thiyagarajan *et al*. 2002) [3, 14, 23]. Kunimitsu (2006) [8] 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. Further, the quantity of water required for generating one kilogram of rice was found to be 1030−3099 and 1078−2531 L of water in SRI-organic and SRI-INM treatments, respectively, compared to 1594−3776 L of water in BMP (Table 6). Thus, it can be concluded that in the SRI method, irrigation use efficiency was higher over the conventional method of rice cultivation.

Table 6: Comparison of water inputs with grain yield as influenced by SRI-organic, SRI-INM and best management practices (BMP)

Seasons	Treatments	Water input (mm ha-1)	Water productivity (kg grain m3)	Litres of water for kg -1 grain	% Water saved over BMP
Kharif 2008	SRI-org	588.5	0.576	1736	23.8
	SRI-INM	716.8	0.731	1368	39.9
	BMP	1068	0.439	2277	
	Mean	791.1	0.582	1794	31.85
Kharif 2009	SRI-org	1146.6	0.323	3099	17.9
	SRI-INM	1336.6	0.395	2531	33
	BMP	1620.1	0.265	3776	
	Mean	1367.8	0.328	3135	25.45
Kharif 2010	SRI-org	1120.5	0.472	2118	31.4
	SRI-INM	1355.2	0.417	2399	22.3
	BMP	1540.4	0.324	3087	
	Mean	1338.7	0.404	2535	26.85
Rabi (2008–09)	SRI-org	730.4	0.707	1340	51.8
	SRI-INM	826.8	0.658	1520	45.3
	BMP	1456.2	0.36	2779	
	Mean	1004.5	0.575	1880	48.55
Rabi (2009–10)	SRI-org	1025.5	0.792	1263	49.6
	SRI-INM	1112.5	0.734	1362	45.7
	BMP	1516.8	0.399	2507	
	Mean	1218.3	0.642	1711	47.65
Rabi (2010–11)	SRI-org	965.1	0.971	1030	35.4
	SRI-INM	1150.5	0.927	1078	32.4
	BMP	1350.5	0.627	1594	
	Mean	1155.4	0.842	1234	33.9

Org = organic; inorg = inorganic

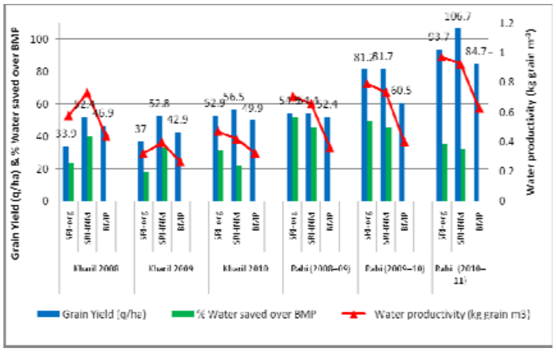

Fig 3: Comparison grain yield, water saved and water productivity as influenced by SRI-organic, SRI-INM and best management practices (BMP)

Discussion

In the present investigation, grain yield was found to be significantly higher in the SRI-INM trials, as compared to BMP. Over the three years of trials, SRI-INM grain yield was greater than with BNM in both seasons, kharif by 15.7%, and rabi by 22.8%, with reduced water requirement of 32 & 41% in kharif and dry seasons. This is clear evidence that SRI management is not only a seed-saving method (5 kg ha^{-1} over 30 kg ha^{-1}), with reduced consumption of water, but also enhances the productivity of the rice.

More research should be done to identify the causal mechanisms between SRI practices and greater populations of beneficial soil microbes, on one hand, and between these populations and the increased grain yield. But the correlations are very evident, and are reported from many evaluations in various countries, although this is the first six-season assessment done under experimental conditions with replications and controls, confirming what has been reported from a variety of other evaluations.

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*., 2010) [4]. Further, long-term research studies at different locations will be useful to quantify the effects of each component of SRI practice, for enhancing resource conservation, for wide-scale adoptability, and for molecular assessments of microbial populations in the soil and the effects of symbiotic endophytes to assess positive soil–plant–microbial interactions.

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