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Article *in* Communications In Soil Science and Plant Analysis · February 2014

DOI: 10.1080/00103624.2013.872250

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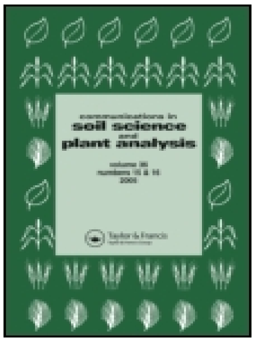

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Communications in Soil Science and Plant Analysis

ISSN: 0010-3624 (Print) 1532-2416 (Online) Journal homepage: https://www.tandfonline.com/loi/lcss20

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Communications in Soil Science and Plant Analysis, 45:415–428, 2014

ISSN: 0010-3624 print / 1532-2416 online
DOI: 10.1080/00103624.2013.872250

Productivity, Nutrient Balance, Soil Quality, and Sustainability of Rice (*Oryza sativa* L.) under Organic and Conventional Production Systems

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A field experiment was conducted for 5 years (2004–2005 to 2009–2010) covering 10 crop seasons [five wet (WS; Kharif*) and five dry (DS;* Rabi*)] at the Directorate of Rice Research farm, Hyderabad, India, to compare the influence of organic and conventional farming systems on productivity of fine grain rice varieties, cumulative partial nutrient balance, and soil health/quality in terms of nutrient availability, physical and biological properties, and sustainability index. Two main plot treatments were with and without plant protection measures, and four subplot treatments were (1) control (CON), (2) inorganic fertilizers (CF), (3) organics (OF), and (4) inorganics + organics (integrated nutrient management, INM). During wet season, grain yields with CF and INM were near stable (5.0 to 5.5 t ha*$^{-1}$*) and superior to organics by 15–20% during the first 2 years, which improved with OF (4.8 to 5.4 t ha*$^{-1}$*) in the later years to comparable levels with CF and INM. However, during DS, CF and INM were superior to OF for 4 consecutive years and OF recorded yields on par with CF and INM in the fifth year. The partial nutrient balance over 10 crop seasons for N and P was positive and greater with OF and INM over CF and for K it was positive with OF alone and negative with CF and INM. There were increases in SOC and available N, P, and K by 50–58%, 3–10%, 10–30%, and 8–25% respectively, with OF, over CF at the end of 5 years. The sustainability index (SI) of the soil system was maximum with organics (1.63) and CF recorded 1.33, which was just above the minimum sustainability index of 1.30 after 5 years. Thus, organic farming needs more than 2 years to stabilize rice productivity and bring about perceptible improvement in soil quality and sustainability in irrigated rice.*

Keywords Grain yield, irrigated rice, nutrient uptake, organic farming, partial nutrient balance, soil sustainability

Introduction

Rice is the most important cereal food crop for more than half of the world's population. Asia, with 60% of the global population, accounts for about 92% of the world's rice production and 90% of global rice consumption. India stands first in area (46 m ha) and second in production (96.0 m tons) among the rice-growing countries. India achieved self-sufficiency in food grain production due to the introduction of high-yielding crop varieties and use of chemical fertilizers, which is commonly referred to the success of

Received 8 December 2011; accepted 13 September 2013.
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green revolution. However, the green revolution has also been associated with several soil and environmental problems due to the indiscriminate use of fertilizers and the soils have become sick from sustained crop production (Evans 2009; Shaik 2009). Imbalanced nutrient management and decreased soil organic matter are the key factors responsible for this decline (Reddy and Krishnaiah 1999) and this may include changes in soil quality parameters (Kang et al. 2005). Soil health degradation has emerged as a major factor responsible for the stagnation in agricultural production. Continuous use of inorganic fertilizers has not only brought about loss of vital soil fauna and flora but also resulted in loss of secondary and micronutrients.

Organic farming has been considered as one of the best options for protecting/sustaining soil health and productivity and is gaining lot of importance in present-day agriculture. Significant improvements in soil physical, fertility, and biological properties have been reported in several organic farming experiments (Carpenter-Boggs, Kennedy, and Reganold 2000; Ramesh et al. 2009). Although grain yield under organic farming is often less than under conventional farming due to so-called organic transition effect, it is feasible to have increased rice yields under the former (Saini and Pandey 2009). Increased sustainability of rice/corn–wheat cropping systems with organic inputs by improving soil nutrients, soil microbial activity, and productive potential of soil was reported by Kang et al. (2005). Use of organic sources in integration with chemical fertilizers to narrow down the gap between addition and removal of nutrients by crops as well as to sustain soil quality and to achieve greater crop productivity was emphasized by Saini and Pandey (2009).

The complete information on organic farming in rice with regard to rice productivity, soil quality, and sustainability in Indian soils is very limited. Hence, the present experiment was conducted to evaluate organic and conventional methods of rice farming systems under Indian conditions in terms of rice productivity, partial nutrient balance, and soil sustainability index.

Materials and Methods

Experimental Site Characteristics

A field experiment was conducted for 5 years (2004–2005 to 2009–2010) covering 10 crop seasons [five wet (WS, *Kharif*) and five dry (DS, *Rabi*)] at the Directorate of Rice Research farm, Hyderabad (17° 19’ N latitude, 78° 23’ E longitude, 542 m in altitude, with a mean annual precipitation of 750 mm), Andhra Pradesh, India, to compare the influence of organic and conventional farming systems on rice productivity, cumulative partial nutrient balance, and soil health/quality in terms of physical, fertility, and biological properties and sustainability index. The experimental soil was deep black clayey soil (Typic Pellustert) with 28% sand, 24% silt, and 48% clay. The experimental soil characteristics were slightly alkaline (pH 8.2), nonsaline [electrical conductivity (EC) 0.7l dS m^{-1}], calcareous [free calcium carbonate ($CaCO_3$) 5.01%], with cation exchange capacity (CEC) 44.1 C mol (p+) kg^{-1} soil and medium soil organic carbon (0.69%) content. Soil available nitrogen (N) was low (228 kg ha^{-1}), available phosphorus (P) was high [105 kg phosphorus pentoxide (P_2O_5) ha^{-1}], available potassium (K) was high [530 kg dipotassium oxide (K_2O) ha^{-1}], and available zinc (Zn) was also high (12.5 ppm). Details of soil and plant analytical methods are explained in the plant and soil studies. The initial bulk density value of the soil measured before the experiment was laid out was 1.42 Mg m^{-3}. The experimental field was under rice cropping for the past 20 years using inorganic fertilizers only.

Treatment Details

There were two main treatments [with plant protection (PP) measures where pesticides were used and without plant protection (NPP) measures], and four subtreatments [CON, control (no fertilizers), CF (conventional fertilizers, 100% inorganic fertilizers), OF (organic fertilizers, 100% organics), and integrated nutrient management (INM; 50% inorganic fertilizers + 50% organics)]. The design used was a split-plot technique with three replications (plot size 80 m^2). The organic sources used were green manure (GM), dhaincha (*Sesbania aculeata*) + paddy straw during wet seasons (WS), and poultry manure (PM) + paddy straw during dry seasons (DS). In *Kharif, Sesbania* green manure crop was grown using 50 kg seed ha^{-1} during May in separate plots for 60 days and then harvested, weighed, chopped, and incorporated as per treatments 1 day before transplanting in the puddled field. Likewise, paddy straw was spread and incorporated in to the soil one day before transplanting of rice. In *Rabi*, poultry manure was applied 1 day before transplanting of rice along with straw.

The local recommended doses of inorganic fertilizers were given at the rate of 100–40–40 kg N, P_2O_5, and K_2O ha^{-1} during WS and 120–40–40–10 kg N, P_2O_5, K_2O, and zinc (Zn) ha^{-1} during DS through urea, single superphosphate, muriate of potash, and zinc sulfate, respectively. Nitrogen was given in three equal splits at basal (before transplanting), maximum tillering (20 days after transplanting), and panicle initiation (40 days after transplanting) stages, whereas P, K, and Zn were given as basal doses only. Through organic fertilizers, the N dose was adjusted to the recommended level based on the moisture content and total N concentration on dry-weight basis.

The straw, green manure, and poultry manure were added to adjust the C/N ratio to about 20–25:1. The nutrient contents of the organic fertilizers on an average for the 10 seasons are shown in Table 1.

Crop Management

During WS (*Kharif*) the rice cultivar BPT-5204 (130 days duration) and in DS (*Rabi*) cultivar Vasumati (120 days duration) were taken up. Thirty-day-old seedlings were transplanted at two seedlings per hill following a spacing of 20 × 15 cm. Two hand weedings were done at 20 days after transplanting (DAT) and 40 DAT, and herbicide was used once in PP plots 4–5 DAT. Appropriate water management was practiced by maintaining water depths of 2–5 cm throughout the crop growth period. Chemical plant protection measures were given to protected plots as per the schedule, and a list of chemicals used is given in Table 2. The wet season crop was transplanted in the first week of July and harvested in the fourth week of October, and the dry season crop was transplanted in the first week of December and harvested in the second week of April.

Table 1
Average nutrient content of organic fertilizers used in the experiment

Organic source	Number of Samples	N content (%)	P content (% P_2O_5)	K content (% K_2O)
Paddy straw	10	0.80	0.20	1.51
Sesbania aculeata	10	2.80	0.22	1.25
Poultry manure	10	2.50	2.00	1.20

Table 2
Details of plant protection (PP) chemicals applied during the experiment

Wet season *(Kharif)*				
WS 2004	WS 2005	WS 2006	WS 2008	WS 2009
Butachlor Furadon (G) Nuvacron Phosphomidon	Butachlor Cartap Furadon (G) Cartap	Butachlor Furadon (G) Nuvacron	Butachlor Furadon (G)	Butachlor Furadon (G)
Dry season *(Rabi)*				
DS 2004–2005	DS 2005–2006	DS 2006–2007	DS 2008–2009	DS 2009–2010
Furadon (G)	Butachlor	Butachlor	No PP Measures	Butachlor
Dursban	Furadon (G) Monochrotophos	Cartap Monochrotophos Furadon (G)		Calden

Plant and Soil Studies

Grain and straw yields (at 14% moisture) were recorded in all 10 seasons. Nutrient accumulation (crop uptake) in both straw and grain was estimated using dry-matter accumulation and nutrient concentrations in grain and straw for each season. Partial nutrient balance was calculated as the difference of nutrients applied (through straw/GM/PM and fertilizers) and crop removal over 10 seasons. At the end of the ninth and tenth seasons, composite soil samples were collected from 0–15 cm deep for each replicate plot by compiling five soil cores. The samples were air dried, processed using a 2-mm sieve, and used for measuring soil fertility, physical, and biological parameters such as pH, EC, available nutrients, soil organic C, bulk density, penetration resistance, enzyme activities, biomass C, biomass N, and soil respiration using standard procedures. Soil reaction (pH) and EC were measured as per Jackson (1973), available N by the alkaline permanganate method (Subbaiah and Asija 1956), available P by sodium bicarbonate ($NaHCO_3$) extraction (Olsen and Sommers 1982), available K by neutral normal ammonium acetate (NH_4OAC) extraction (Knudsen, Peterson, and Pratt 1982) and available Zn by diethylenetriaminepentaacetic acid (DTPA) extraction (Lindsay and Norvel 1978). Organic C was estimated in finely powdered (0.5 mm sieved) soil by Walkley and Black (1934) method using potassium dichromate. For measuring soil respiration rate, field moist soil samples were collected from 0–15 cm deep after harvest and the method of estimation was carbon dioxide (CO_2) trapping in sodium hydroxide (NaOH) (Ohlinger 1996).

Soil microorganisms were enumerated by soil dilution and plating on appropriate media for *Azotobacter* (Brown, Burlingham, and Jackson 1962), phosphate-solubilizing bacteria (Pikovskaya 1948), and by most probable number (MPN) technique for *Azospirillum* (Dobereiner and Day 1976). Soil microbial biomass C (SMB-C) and soil microbial biomass N (SMB-N) were estimated by chloroform–fumigation–extraction (CFE) according to Vance, Brookes, and Jenkinson (1987) and Brookes et al. (1985), respectively. β-Glucosidase activity was determined as described by Eivazi and Tabatabai

(1988), alkaline phosphatase was assessed by the method of Tabatabai and Bremner (1969), and dehydrogenase activity was measured according to Tabatabai's (1982) method.

Soil Quality and Sustainability Indices

By using different approaches such as nutrient index, microbial index, and crop index, different production systems (CON, CF, OF, and INM) were compared and soil sustainability index was calculated as per the procedure given by Kang et al. (2005) at the end of the second and fifth years. A triangular approach was used to evaluate the sustainability of a system. This approach is based on measurements of crop index (CI; calculated from grain yield and N, P, and K uptake by crop), soil nutrient index (NI; calculated from pH, E.C, organic C, available N, $NaHCO_3$-extractable P, NH_4OAc-extractable K, and DTPA-extractable Zn contents), and soil microbial index (MI; calculated from soil respiration, microbial biomass C and N, microbial counts, and enzyme activities). Most of the selected parameters are as per the minimum data set (MSD) proposed by Larson and Pierce (1991) for assessing soil health.

The crop index was calculated by determining the four crop parameters: grain yield and N, P, and K uptake. The crop index for each treatment was measured as an average of index values of all the four parameters in each treatment. The nutrient index was calculated by determining the following seven chemical parameters: pH, EC, organic C, available N, $NaHCO_3$-extractable P, NH_4OAc-extractable K, and DTPA-extractable Zn contents. The nutrient index for each treatment was calculated as an average of index values of all the seven parameters in each treatment.

Microbial index of soil was calculated from the measured nine microbial parameters: microbial biomass C, microbial biomass N, soil respiration, N-fixing bacteria (*Azotobacter, Azospirillum*), phosphate-solubilizing bacteria, ß-glucosidase, alkaline-phosphatase, and dehydrogenase activities. The microbial index for each treatment was calculated as an average of index values of all the nine parameters in each treatment. The sustainability index of the soil was measured as the area of the triangle with nutrient index, microbial index, and crop index of soil at three vertices (Kang et al. 2005).

Statistical Analysis

The data pertaining to the observed characteristics of rice crop were analyzed statistically by applying analysis of variance (ANOVA) for split-plot design. Least significant differences (LSD) were conducted at a 5% level of probability, where significance was indicated by F-test (Gomez and Gomez 1984).

Results and Discussion

Grain Yield

With regard to plant protection measures, the differences in grain yield between protected and unprotected plots was only marginal/negligible except in two wet seasons (WS 2005 and 2006) where protected plots recorded 14 and 13% greater yield, respectively. This was due to very low pest incidence during most of the study period. With regard to nutrient sources, during WS, grain yields in the inorganic fertilizer (CF) applied and INM plots were near stable, ranging from 5.3 to 5.5 and from 5.0 to 5.2 t ha^{-1}, respectively, and superior to organics during the first 2 years (2004–2006) by 15–20%, which improved with organics (4.8–5.4 t ha^{-1}) in the later years to comparable levels with inorganics and INM (Table 3).

During DS, however, INM (3.6–4.3 t ha^{-1}) and CF (3.7–3.8 t ha^{-1}) were superior to organics (3.1–3.5 t ha^{-1}) for 4 consecutive years and organics recorded (4.0 t ha^{-1}) yields on par with CF (4.2 t ha^{-1}) and INM (4.1 t ha^{-1}) in the fifth year only. This could be due to mismatch of nutrients release from organic sources and crop demand as influenced by seasonal conditions in the initial years. Once the soil fertility was built up sufficiently, the organic system produced yields equal to the conventional system. Thus, slow and gradual release of nutrients from organics during the initial years of conversion to organic farming could not result in increased yields, but repeated application of organics over the years built up sufficient soil fertility by improving soil biological activity.

The recession in the crop yields during initial phase of transition from conventional to organic agriculture and recovery in yields after 2–3 years was reported by Sharma and Mohan Singh (2004) and Ramesh et al. (2009). Yield losses of organically grown rice of 24% are reported (Mader et al. 2002), though organic farming system showed efficient resource utilization. Tamaki, Itani, and Nakano (2002) studied the growth and yield of rice with organic farming in comparison with conventional farming in Japan and found that the growth and yield of rice increased with continuous organic farming. Greater grain yield with combination of FYM/ vermicompost + wheat residue + biofertilizers under organic farming of basmati rice was reported by Davari and Sharma (2010). Similar results of gradual increases in rice grain yield with the use of organics over a period of time were also observed by Urkurkar, Chitale, and Tiwari (2010). Unfertilized control treatment recorded the lowest grain yields throughout the experiment. It is obvious that all fertilization caused large yield increases, but yields were generally less in the DS. These lesser grain yields in DS compared to WS could be ascribed to the varietal difference: the Vasumati variety used in the DS was aromatic, and in general the yield levels of aromatic rice are poor.

Nutrient Uptake and Partial Nutrient Balance

The pattern of total nutrient uptake followed almost the same trend as grain yield in case of N and P uptake (Table 4). During WS, N uptake was significantly greater with CF and INM compared to OF in the initial 2 years, and from year 3 onward these three treatments were on par. During DS, these three treatments on par with regard to N uptake in the fifth year only. With regard to P uptake, there was no significant difference among these three treatments in all 10 seasons. The K uptake also followed the same trend as N, where CF and INM recorded significantly greater K uptake over OF in the first 2 years during WS and this trend continued until the 4th year during DS, whereas CF, INM, and OF recorded similar K uptake from third and fifth years during WS and DS, respectively. Kumari et al. (2010), in a 2-year study with scented rice, observed greater nutrient uptake with greater yields achieved in chemical fertilizer treatment compared to organics alone. Significant increases in dry-matter yield and nutrient uptake with organic fertilization in long-term field experiments of rice–wheat system were reported by Kang et al. (2005).

The cumulative partial nutrient balance over 10 seasons for N, P, and K is presented in Figure 1. Nitrogen addition was the same (1100 kg ha^{-1}) in all the treatments. Nitrogen removal by crop was greatest in the treatment with CF (817 kg ha^{-1}) followed by INM (777 kg ha^{-1}) and OF recorded comparatively lower removal (711 kg ha^{-1}) there by recording greater partial N balance (389 kg ha^{-1}). With regard to P, maximum addition was through OF (425 kg ha^{-1}) followed by INM (412 kg ha^{-1}) and CF (400 kg ha^{-1}). The P removal was slightly greater with CF (122 kg ha^{-1}) followed by INM (119 kg ha^{-1}) and

Table 3

Grain yield (t/ha) as influenced by nutrient sources and plant protection measures

Wet season (*Kharif*)															
	WS 2004			WS 2005			WS 2006			WS 2008			WS 2009		
Treatment	NPP	PP	Mean	NPP	PP	Mean	NPP	PP	Mean	NPP	PP	Mean	NPP	PP	Mean	Pooled mean
CON	3.32	3.59	3.45	3.17	3.55	3.36	2.94	3.32	3.13	3.23	3.43	3.33	3.05	3.34	3.19	3.29
CF	5.42	5.52	5.47	5.07	5.63	5.35	4.90	5.50	5.20	5.13	5.52	5.33	5.18	5.29	5.23	5.31
OF	4.44	4.92	4.68	4.26	4.92	4.59	4.52	5.22	4.85	4.87	5.60	5.23	5.45	5.27	5.36	4.94
INM	4.84	5.17	5.00	4.75	5.56	5.15	4.76	5.31	5.03	4.73	5.48	5.12	5.14	5.02	5.08	5.07
Mean	4.50	4.80	4.65	4.31	4.91	4.61	4.28	4.84	4.56	4.49	5.01	4.75	4.70	4.73	4.71	4.65
LSD	Main-NS			Main-0.356			Main-0.425			Main-NS			Main-NS			
($P = 0.05$)	Sub-0.690			Sub-0.427			Sub-0.398			Sub-0.667			Sub-0.604			
	MxS-NS			MxS-NS			MxS-NS			MxS-NS			MxS-NS			

Dry season (*Rabi*)															
Treatment	DS 2004–2005			DS 2005–2006			DS 2006–2007			DS 2008–2009			DS 2009–2010			
	NPP	PP	Mean	NPP	PP	Mean	NPP	PP	Mean	NPP	PP	Mean	NPP	PP	Mean	Pooled mean
CON	2.13	1.92	2.03	2.11	2.33	2.17	2.18	2.77	2.48	2.04	1.98	2.01	2.12	2.13	2.12	2.16
CF	3.76	3.82	3.79	3.67	3.81	3.74	3.40	4.22	3.81	3.87	3.74	3.81	4.15	4.21	4.18	3.86
OF	3.42	3.62	3.52	3.10	3.11	3.10	2.91	3.37	3.14	3.51	3.14	3.32	3.99	3.98	3.98	3.41
INM	4.2	4.36	4.28	3.43	3.81	3.62	3.50	4.04	3.77	3.72	3.82	3.77	4.05	4.22	4.13	3.91
Mean	3.38	3.43	3.40	3.08	3.26	3.17	3.00	3.60	3.30	3.28	3.17	3.22	3.57	3.63	3.60	3.33
LSD	Main-NS			Main-NS			Main-NS			Main-NS			Main-NS			
($P = 0.05$)	Sub-0.630			Sub-0.505			Sub-0.556			Sub-0.444			Sub-0.359			
	MxS-NS			MxS-NS			MxS-NS			MxS-NS			MxS-NS			

Table 4
Total nutrients uptake (kg ha^{-1}) as influenced by different nutrient sources

Treatment	Wet season (*Kharif*)						Dry season (*Rabi*)					
	Y 1	Y 2	Y 3	Y 4	Y 5	Mean	Y 1	Y 2	Y 3	Y 4	Y 5	Mean
						Nitrogen (kg ha^{-1})						
CON	51.3	64.6	52.6	56	49.3	54.76	33	39.5	47	38.4	40	39.58
CF	91.3	109	83.2	96.7	76.8	91.4	62	69.7	68	72.8	87.5	72
OF	76.1	89	81.2	87.8	80.4	82.9	54.8	50.4	58	61	72.4	59.32
INM	67.5	115	82.2	90.1	79.6	86.88	66.5	60.4	70	66.6	78.8	68.46
LSD ($P = 0.05$)	9.55	8.7	5.4	10.5	10.0		7.3	6.2	8.5	6.6	7.9	
						Phosphorus (kg ha^{-1})						
CON	11.3	5.74	9.47	8.1	10.4	9.00	5.35	6.92	9.8	5.54	5.7	6.66
CF	15.2	8.13	16.4	12.4	15.6	13.55	8.6	13.88	12.8	9.02	10.5	10.96
OF	14.8	7.15	15.68	12.6	16.7	13.39	8.8	11.03	11.8	9.12	9.9	10.13
INM	12.9	7.13	15.68	11.7	15.9	12.66	8.37	12.62	14.8	9.46	10.4	11.13
LSD ($P = 0.05$)	3.66	1.22	1.32	2.63	1.94		2.6	3.95	2.1	2.8	2.6	
						Potassium (kg ha^{-1})						
CON	48.2	53.5	58.9	68.3	62.5	58.28	35.0	34.8	57.1	46.7	50.2	44.71
CF	79.8	93.3	90.4	92.9	78.3	86.94	57.8	89.4	81.0	64.9	100.1	78.64
OF	71.5	71.3	81.9	93.1	88.2	81.2	47.3	61.0	81.1	61.3	88.3	67.78
INM	63.2	74.6	85.8	93.8	76.5	78.78	51.5	67.6	102.1	62.9	97.1	76.22
LSD ($P = 0.05$)	10.9	9.6	18.8	17.5	23.5		16.1	14.2	23.6	25.3	24.1	

Note. Y1, Y2, Y3, Y4, and Y5 are years 1, 2, 3, 4 and 5, respectively.

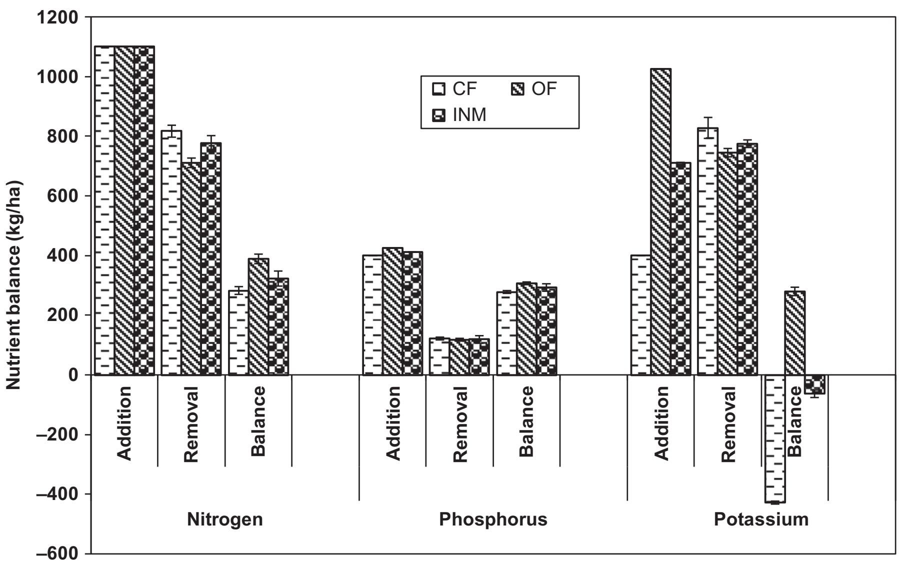

Figure 1. Partial nutrient balance (kg ha^{-1}) over 10 crop seasons as influenced by different nutrient sources.

OF (118 kg ha^{-1}). The partial P balance was maximum with OF (307 kg ha^{-1}), followed by INM (293 kg ha^{-1}) and CF (278 kg ha^{-1}). The cumulative nutrient balances for N and P were greater with organics (OF) by 37.3 and 10.4% and with INM by 14.1 and 5.4%, respectively, over inorganics (CF) alone.

In the case of K, maximum addition was through OF (1025 kg ha^{-1}) followed by INM (712 kg ha^{-1}) and CF (400 kg ha^{-1}), whereas K removal was the reverse: it was maximum with CF (828 kg ha^{-1}), followed by IMN (775 kg ha^{-1}) and OF (745 kg ha^{-1}). All organic sources were rich in K content and added more K to the soil without showing large variation in removal. This has resulted in positive K balance in the case of OF (280 kg ha^{-1}) alone. Negative K balance was recorded with CF (–428 kg ha^{-1}) and INM (–63 kg ha^{-1}), indicating depletion of soil K reserves. More positive nutrient balances with organic manures in cases of N, P, and K and a negative balance for N and K with chemical fertilizers were reported by Saha et al. (2007) and Yadav, Kumar, and Yadav (2009) in rice-based cropping systems.

Soil Properties

Changes in soil properties were monitored at the end of 5 years, and results are presented in Table 5. There was a significant improvement in soil physical (bulk density and penetration resistance), fertility (organic C and available N, P, and K), and biological properties (microbial populations, BM-C, BM-N, soil respiration, and enzyme activities including glucosidase, phosphatase, dehydrogenase, and sulfatase) with organics compared to inorganic fertilizers and INM. Compared to inorganics, there were increases in SOC and available N, P, and K of 50–58%, 3–10%, 10–30%, and 8–25% with organics, respectively, at the end of 5 years. Paddy straw, being rich in K, and poultry manure, with high P content, are the possible factors responsible for the observed increases in soil P and K values in treatments where these two organic sources were used. A further reason for the SOC increase may be the slow decomposition of applied and native soil organic matter due to prevailing anoxic conditions and formation of difficult-to-decompose SOC under a rice–rice system (Ponnamperuma 1984). Reductions in bulk density with the application of organic manures were reported by Prakash, Bhadoria, and Rakshit (2002) and Ramesh et al. (2009). Superior soil fertility status on organic farms compared to soils fertilized with chemical fertilizers was reported by Sharma and Singh (2004), Kharub and Chander (2008), and Kumari et al. (2010).

Organic nutrient sources showed a stimulating influence on the soil microbial communities as seen by the increase in microbial populations (Table 5). The N-fixing microbial populations such as *Azotobacter, Azospirillum,* and phosphate-solubilizing bacteria (PSB) were significantly greater with organics [5.12, 4.06, and 4.26 log colony-forming units (CFU) g^{-1} soil, respectively] as compared to inorganics with 4.14, 3.81, and 4.04 log CFU g^{-1} soil, respectively. Increased availability of substrates (C and N) required for microbial population buildup could be the probable reason for this increase (Bunemann, Schwenke, and Van Zwieten 2006). Enzyme activities in soil were also influenced by different treatments. β-Glucosidase, which is involved in C cycling; alkaline phosphatase, which plays a major role in the mineralization of organic phosphorus substrates; and dehydrogenase, which is an indicator of total microbial activity, were significantly greater with organics compared to inorganics and INM. Extracellular enzyme activities (alkaline phosphatase, protease, and β-glucosidase) have been reported to be greater in soils under organic management than under conventional management because the addition of organic amendments activates microorganisms to produce enzymes (Melero et al. 2008).

Significant increases in microbial biomass C and N also recorded with organics over the other three treatments. Soil respiration rate, another important indicator of soil biological activity, was also significantly greater with organics than with inorganics. Organic sources provide a stable supply of C and energy for microorganisms and cause an increase

Table 5

Soil properties of different production systems at the end of the fifth year

Wet season (*Kharif* 2009)

Treatment	Physical	Fertility					Biological			
	BD	SOC (%)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Zinc (ppm)	SR	BG	AP	DH
CON	1.36	0.59	213	92	508	10.0	0.158	573	325	95
CF	1.42	0.64	225	167	548	12.1	0.173	827	458	140
OF	1.29	1.01	231	184	592	15.3	0.208	1158	563	162
INM	1.34	0.91	227	172	545	14.4	0.183	1021	488	145
LSD (0.005)	0.069	0.116	*NS*	14	41	2.5	0.024	92	76.9	20.5

Dry season (*Rabi* 2009–2010)

Treatment	Physical		Fertility				Biological					Nitrogen-fixing bacteria (log CFU g^{-1} soil)		
	BD	PR (kg/cm^2)	SOC (%)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	SR	AP	BG	BM-C	BM-N	AB	Azo	PSB (log CFU g^{-1} soil)
CON	1.38	10.20	0.54	197	80	463	0.132	179	82	456	249	5.08	4.58	4.30
CF	1.45	11.85	0.60	206	168	493	0.139	250	83	560	276	4.70	4.36	4.43
OF	1.30	7.68	0.90	227	219	617	0.179	306	112	988	377	5.72	4.62	4.66
INM	1.32	9.52	0.79	220	188	537	0.167	261	101	760	331	5.64	4.62	4.58
LSD (0.005)	0.072	1.45	0.159	*NS*	26	38	0.028	26.5	14.9	137	53.61	0.0129	0.0126	0.0136

Notes. BD, bulk density (Mg/m3); SOC, soil organic carbon; PR, penetration resistance; SR, soil respiration (mg CO_2 / g soil / 24h); BG, beta-glucosidase (µg p-nitrophenol / g soil / h); AP, alkaline phosphatase (µg p-nitrophenol / g soil / h); DH, dehydrogenase (µg triphenyl formazon / g soil / 24 h); BM-C, biomass carbon (µg C g^{-1}soil); BM-N, biomass nitrogen (µg N g^{-1}soil); AB, azotobacter; Azo, azospirilllum; PSB, phosphate-solubizing bacteria.

in the microbial biomass pool, thereby increasing soil respiration rate. Greater respiration rates in organically managed soils than in conventionally managed soils and favorable improvement in soil physical, fertility, and biological properties were reported in organic farming experiments by Carpenter-Boggs et al. (2000).

Soil Quality and Sustainability Indices

Soil quality and sustainability indices were calculated using crop and soil characteristics and depicted in Figure 2. The nutrient index (NI), which represents the availability of nutrients in soil, and microbial index (MI), which indicates the biological activities in soil, were greater with OF (1.13 and 1.14) followed by INM (1.04 and 1.06) and CF (1.00 and 0.95). CON (0.84 and 0.86) recorded the lowest values at the end of second as well as fifth years. The crop index, measured by grain yield and nutrient uptake, was greater with CF (1.19) followed by INM (1.09) and OF (0.98) at the end of second year, and it was maximum with CF (1.12) followed by OF (1.08) and INM (1.07) at the end of fifth year. The difference in CI between CF and OF narrowed down by the end of fifth year to 4.0%

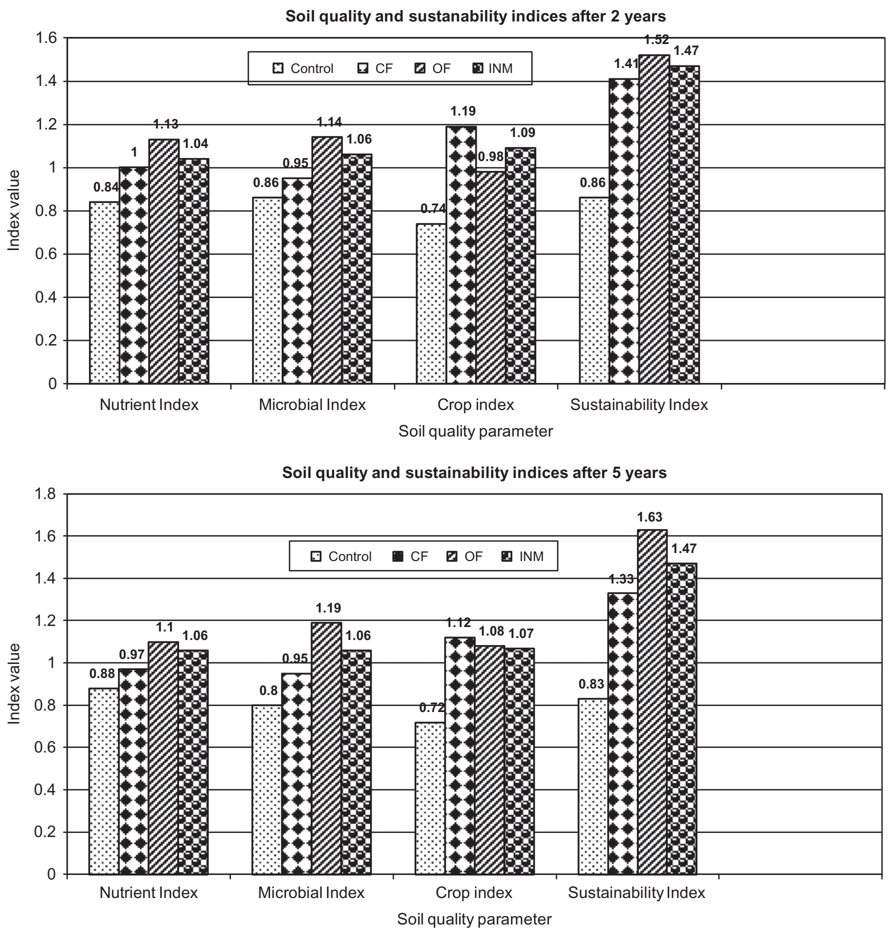

Figure 2. Soil quality and sustainability indices as influenced by different nutrient-management practices.

from 21.0% at the end of second year. This could be attributed to the improvement in grain yield and nutrients uptake in OF treatment that resulted in better CI in this treatment compared to initial years.

The sustainability index (SI), of the soil system, measured from these three indices was maximum with OF (1.52) followed by INM (1.47) and CF (1.41) at the end of second year. Interestingly, the SI at the end of fifth year still improved in the OF system (1.63) and decreased with CF (1.33), which was just above the minimum sustainability index of 1.30 as explained by Kang et al. (2005). Though CI was more with CF, due to higher NI and MI, OF recorded maximum SI compared to CF. The SI of INM remained same in both years. The control treatment was characterized by the lowest indices. This clearly shows that SI of the system will be improved over the years with OF, will be decreased with CF alone, and will be maintained as such with INM. Kang et al. (2005) also reported that application of rice straw compost alone for 4 years gave a sustainability index of 1.69, compared to the unsustainable chemical fertilizer system, which recorded a sustainability index of 1.07 in a rice–wheat cropping system. They also reported in an 18-year long-term experiment of rice–wheat system that FYM + GM treatment recorded a SI of 2.20 against the SI of only 1.16 in the case of chemical fertilizers alone. Biswas and Benbi (1997) also observed that chemical fertilizers were unable to sustain high yields in a long-term experiment with maize and wheat.

Conclusions

From the present 5-year study of crop productivity, partial nutrient balance, soil fertility, and sustainability index under organic and conventional rice production systems, it can be concluded that in the initial years of experimentation when the field was under transition, organic fertilizers did not result in increased yields, and chemical fertilizers and INM were found superior. However, repeated application of organics over the years resulted in sufficient buildup of soil fertility and improved the grain yield. Further, organic production systems improved the cumulative partial nutrient balance, soil quality indices, and sustainability index of the soil when compared to conventional production system.

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