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Integrated resource management improves soil glucosidase, urease, and phosphatase activities and soil fertility during rice cultivation in Indo-Gangetic plains

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Abstract: The sustainable cultivation of rice (*Oryza sativa* L.) without compromising yield is an emerging challenge. Field experiments were conducted at New Delhi, during 2007 and 2008 to investigate the effect of tillage, irrigation regimes, and integrated nutrient management practices on the soil enzymatic and microbial activities. The soil glucosidase (67.35%) and urease (106.75%) increased under conservation tillage compared with conventional tillage; largest increase was observed when a combination of 50% farm yard manure + 25% biofertilizer + 25% green manure (GM) was used in place of recommended dose of nitrogen (RDN) or when 25% RDN was replaced with biofertilizer or GM as nutrients in combination with conservation tillage and optimum water supply (three-irrigations) with a few exceptions. The present study has suggested that resource management practices significantly improved soil enzymatic and microbial activities under conservation tillage and optimal water supply which reduce the dependence on chemical fertilizers and make rice cultivation sustainable.

Subjects: Agriculture & Environmental Sciences; Agronomy; Environment & Agriculture; Environmental Sciences; Soil Conservation Technology; Soil Sciences

ABOUT THE AUTHORS

The activity of our research group at the Division of Microbiology, Indian Agricultural research institute (New Delhi), is mainly related to the improvement of rice–wheat cropping system in Indo-Gangetic plains by integrated resource management (IRM) practice, to minimize cost of production, reduce environmental damage in developing countries, and improving food security in the developing countries. The research reported in the paper pertains to observe the effect of resource management on soil enzyme activity and hence soil fertility during rice crop cultivation. High input of resources like chemical fertilizers, tillage, and water pollutes the environment and harms soil fauna. The present research demonstrates that integrated and optimum use of resources improves soil glucosidase, urease, and phosphatase activity and overall microbial activity of soil and thus fertility of soil by mixed use of organic and chemical fertilizers and optimum use of other high input resources.

PUBLIC INTEREST STATEMENT

Public concerns against input intensive agriculture include excessive use of chemical fertilizers, which reportedly leach into soil and water and pollute them. The present study demonstrates that integrated use of chemical and organic fertilizers, optimum irrigation, and minimum tillage can reduce the dependence on resources besides improving soil enzyme activity and fertility. It was observed in our study that important soil enzyme activities like glucosidase, urease, alkaline, and acid phosphatase which circulate carbon, nitrogen. and phosphorous. An increase in soil microbial activity was also observed. These observations confirmed increase in soil microbial activity and fertility. To check whether it affects overall metabolic activity, soil respiration and soil microbial biomass carbon were calculated. It was observed that overall metabolic quotient of soil decreased (i.e. increase in microbial activity) when organic fertilizers were used as compared to complete chemical fertilizer treatment suggesting the improvement of soil fertility.

Keywords: conservation tillage; optimal drainage; integrated nutrient management (INM); soil enzymatic activities; soil microbial activities; *Oryza sativa* L.

1. Introduction

Rice is the staple diet of more than 65% of Indian population (Ghosh, 2009) which is grown on 44 million hectares of land (AIREA, 2012). The green revolution practices of the 1960s have been based on the application of relatively high rates of chemical fertilizers, tillage practices, and irrigation. However, the above-stated practices have proved to be insufficient in meeting the challenges of enhanced and sustainable productivity. Besides, the burgeoning problem of global warming also warrants the need to change conventional practices to reduce greenhouse gas emissions (You, Rosegrant, Fang, & Wood, 2005).

The excessive use of chemical fertilizers and energy-intensive processes, such as tillage and irrigation, has led to the distortion of soil physical and biological status in many agricultural ecosystems (Liu et al., 2005). On the other hand, resource–conservation technologies reduce dependence on resource–intensive processes (Erenstein, 2009) and make agriculture sustainable.

The soil enzymatic activities are considered a major index for soil microbial activity and soil organic carbon status (Bandick & Dick, 1999). The glucosidase and urease are among the prominent soil enzymes. The glucosidase reflects soil-management effects and has microbial significance because of its role in C-cycle (Bilen, Celik, & Altikat, 2010). Similarly, urease and phosphatase activity is responsible for N- and P-metabolism in the soil (Li et al., 2010; Rahmansyah, Antonius, & Sulistinah, 2009). There are only a few studies that have considered resource conservation (i.e. tillage, fertilizer, and irrigation) to determine improved soil and agricultural practices in Indo-Gangetic plains (IGP) for rice. Mahajan and Gupta (2009) reported the need for integrated nutrient management (INM) practices in South Asia to make agriculture sustainable. However, an integrated approach for tillage, water, and nutrient management for rice crop involving soil biological indices, i.e. soil glucosidase, urease, and phosphatase (for C, N, P circulation, respectively) has not been reported.

The sustainable cultivation of rice crop without compromising yield could help in reducing the overbearing pressure on resources, such as water and chemical fertilizers, without polluting the environment. The present study was planned to determine the optimum requirements for tillage, water, and nutrients in a sandy loam soil of IGP at Delhi, for rice crop, which can help in increasing the activity of soil glucosidase, urease, and phosphatase.

2. Materials and methods

2.1. Experimental location

Field experiments were conducted at the research farm of Indian Agricultural Research Institute, New Delhi, (Latitude: 28°38′ N, Longitude: 77°12′ E, Altitude: 216 msl) during the summer (*kharif*) season of 2007 and 2008. New Delhi has semi-arid and sub-tropical climate with hot and dry summers and cold winters. It falls under the agro-climate zone called “Trans-Gangetic plains,” where summer months (May and June) are the hottest, with the maximum temperature ranging between 41 and 48°C, whereas January is the coldest, with the minimum temperature ranging between 3 and 7°C.

The temperature rises gradually through the months of February and March and it reaches the maximum during June, and falls slightly with the advent of southwest monsoon rain. The mean precipitation for Delhi is 650 mm, which is mostly received during July to September and occasionally during winter.

2.2. Experimental design

Two experiments were laid out in a split-plot design with three replicates each. Two tillage treatments (i.e. conservation and conventional), were assigned to main plots and three irrigation treatments [i.e. sub-optimum (two-irrigation regime), optimum (three-irrigation regime), and supra-optimum (five-

Table 1. Details of various nutrient combinations used under integrated nutrient-management practices

Treatments (T)	Composition
T_0	Control (No external nutrients were supplied)
T_1	Recommended dose of Nitrogen (RDN) through urea + 33 kg ha^{-1}, Phosphorus (P) added as rock phosphate, No Potassium (K) added (i.e. RDN = 120 kg ha^{-1})
T_2	75% RDN through urea + 25% RDN through farmyard manure (FYM) + PK
T_3	75% RDN through urea + 25% RDN through green manure (GM) + PK
T_4	75% RDN through urea + 25% RDN through biofertilizer (Azospirillium) + PK
T_5	75% RDN through urea + 25% RDN through sewage sludge + PK
T_6	50% RDN as FYM + 25% RDN through biofertilizer + 25% RDN through green manure + PK
T_7	Blank (i.e. fallow) plot

irrigation regime)] were assigned to sub-plots (each at a gap of 20 days). The sub-plots were further divided into sub-sub-plots for different nutrient treatments as shown in Table 1.

During the period of 2003–2007 tillage, water and nutrient management had been practiced in the field on different crops (i.e. all crops were subjected to the same practices) (Table 2). The rice cultivar (cv.) “Pusa Sugandh 3” seeds were sown during the first week of June 2007 and 2008 at a spacing of 20 × 15 cm. A uniform dose of 33 kg ha^{-1} P was made available through single superphosphate and 37 kg ha^{-1} of K made available through muriate of potash. Both single superphosphate and muriate of potash were applied to the plots before sowing. The chemical N fertilizer (urea) was applied in three split doses, i.e. half as basal dose and the other two doses in two equal parts as top dressing at tillering and at panicle initiation stages of rice. The six INM treatments are given in Table 2. The control plot refers to no input of N, whereas blank plot refers to uncultivated soil.

The well decomposed farm yard manure (FYM) containing 0.5% N (i.e. 0.05 kg N kg^{-1} of FYM) on a dry-weight basis calculated by Kjeldahl’s method was incorporated in the soil as green manure (GM) before sowing, as a substitute for chemical fertilizers. Similarly, *Sesbania aculeate* was added as a GM at 10.5 t ha^{-1} before seeding of rice in the same experiment. One fourth of urea was replaced by biofertilizer (*Azospirillium brasilense*) CDJA received from Dr J. Dobereiner, Brazil. The *A. brasilense* strain fixes 25–30% [of recommended dose of nitrogen (RDN)] N ha^{-1}. The coating of seeds was done by dipping the seeds in an aqueous suspension culture of the biofertilizer. The inoculum density was 10^8 cells ml^{-1} (Zorita & Canigia, 2008). A measured quantity of water through a 7.62 cm Parshall flume was applied at the rate of 40 mm at each irrigation time, as per treatment. During the crop period, total rainfall received in 2007 was 112.0 mm and that in 2008, 111.8 mm. Relative humidity in 2007 was 71% and that in 2008, 68.2 for the month of January, and mean temperature in 2007 was 18.24°C and in 2008, 18.46°C.

Table 2. Cropping history of the experimental field from 2003 to 2006

Year	Kharif	Rabi	Summer
2001–2002	Rice	Wheat	—
2002–2003	Rice	Wheat	—
2003–2004	Rice	Wheat	—
2004–2005	Rice	Wheat	—
2005–2006	Rice	Wheat	Mungbean
2006–2007	Rice	Wheat	Mungbean

Table 3. Some important physical and chemical characteristics of soil

Parameter	Observation
Type of soil (0–15 cm)	Sandy clay-loam
Field capacity	19–20% (w w^{-1})
Permanent wilting point	7–11% (w w^{-1})
pH	7.7
Organic C	0.68 (kg ha^{-1})
Alkaline permanganate hydrolyzable N	159–163 (kg ha^{-1})
0.5 m $NaHCO_3$ extractable P	14 (kg ha^{-1})
1 N NH_4OAc exchangeable K	296 (kg ha^{-1})

Note: The above-stated parameters have also been reported by Singh, Kumar, Marwaha, and Singh (2009).

2.3. Soil sampling and physical and chemical characteristics of soil

The soil type in IARI fields (New Delhi) is Typic Haplustept (Saha et al., 2010). The moist soil was sieved (2 mm mesh size), homogenized, and stored at 4°C. The gravimetric moisture content was determined immediately. Microbial analysis of the soil samples was done using fresh soil samples, and the results were expressed on dry weight basis. Some important physical and chemical characteristics of soil are given in Table 3.

2.4. Determination of glucosidase (μg NPG per g^{-1}), urease (μg N g^{-1} soil h^{-1}), acid phosphatase (μg PNPP g^{-1} soil h^{-1}), and alkaline phosphatase (μg PNPP g^{-1} soil h^{-1}) activity in the field soil

Soil samples were collected from a depth of 0–15 cm after harvesting rice crop. Six sub-samples per treatment were composited. The field-moist samples were sieved to 2 mm and analyzed for: soil glucosidase, soil urease, acid phosphatase, and alkaline phosphatase. Soil glucosidase (EC, i.e. enzyme commission number—3.2.1.21) activity was measured using the procedure proposed by Wood and Bhat (1988). Soil urease (EC number—3.5.1.5) activity was measured in the field-moist samples using the following procedure proposed by Tabatabai and Bremner (1972). Soil acid phosphatase (EC number—3.1.3.1) activity was measured by using the procedure proposed by Tabatabai and Bremner (1969), and alkaline phosphatase (EC number—3.1.3.2) activity was measured according to Eivazi and Tabatabai (1977).

2.5. Estimation of soil respiration, dehydrogenase, and soil microbial biomass carbon

Soil samples were collected from a depth of 0–15 cm immediately after the harvest of rice crop. Six sub-samples per treatment were composited. The field-moist samples were sieved to 2 mm and analyzed for: respiration, dehydrogenase activity (DHA), and soil microbial biomass carbon (SMBC) content in the soil. The SMBC was estimated following chloroform fumigation extraction method of Vance, Brookes, and Jenkinson (1987). The soil respiration (SR) was measured according to Stotzky (1965). The soil dehydrogenase enzyme (DH) activity was determined via the method used by Casida, Klein, and Santoro (1964). The metabolic quotient (qCO_2; i.e. the respiration to biomass ratio) was calculated from basal respiration (CO_2–C h^{-1}) per unit SMBC (C-mineralized) (Tischer, 2005).

$$qCO_2 = \text{Basal respiration} \times 1000/\text{SMBC}$$

2.6. Number of grains per panicle

From the 10 selected panicles of rice plants, cleaned, filled, and unfilled grains were separated. The filled grains were counted with the help of a seed counter. The mean value of filled grains per panicle was computed.

2.7. Statistical analysis

All the data recorded were analyzed using the standard procedure of statistical analysis for a split-plot design (Gomez & Gomez, 1984). Analysis of variance (ANOVA) was used to determine the effect of each treatment. A multiple-mean comparison was performed using CD (critical difference) (0.05 probability level) values. The data were analyzed via MSTAT statistical package.

3. Results

3.1. Soil glucosidase activity

The soil glucosidase activity increased significantly (i.e. 67%) in zero-tillage plots compared to the conventional tillage plots (Table 4). Among INM treatments, the highest rate of soil glucosidase activity was recorded in the treatment where N was made available through a sole organic source of N (i.e. 32.85 µg NPG (p-nitrophenyl-β-D-glucoside) per g^{-1} soil), followed by the treatment where 25% RDN was replaced with FYM (i.e. 32.11 µg NPG per g^{-1} soil). The increase in soil glucosidase activity has been significantly ($p < 0.05$) greater compared to the control plots. For a given nutrient-management practice, the three different water regimes significantly affected the soil glucosidase activity. Soil receiving sole organic source for the three-irrigation regime (optimum) recorded 16 and 22%

Table 4. Effects of tillage, soil regimes, and integrated nitrogen management practices on soil glucosidase, urease, and phosphatase (acid and alkaline) activities in rice cultivated using different tillage, irrigation regimes, and nutrition treatments

Treatments	Soil glucosidase activity (µg NPG per g^{-1})	Soil urease activity (µg N g^{-1} soil h^{-1})	Acid phosphatase activity (µg PNPP g^{-1} soil h^{-1})	Alkaline phosphatase activity (µg PNPP g^{-1} soil h^{-1})
Tillage (T)	**Rice**	**Rice**	**Rice**	**Rice**
Conservation tillage	34.86 ± 1.46b	180.47 ± 7.39b	65.07 ± 2.60b	172.62 ± 6.90b
Conventional tillage	20.83 ± 0.79a	87.29 ± 3.40a	30.28 ± 1.15a	84.35 ± 3.20a
CD (0.05)	0.65	0.75	0.79	3.72
Irrigation (Irr)				
Sub-optimal	27.94 ± 1.06b	138.49 ± 5.40b	40.82 ± 1.63a	134.07 ± 5.20b
Optimum	29.98 ± 1.13c	131.94 ± 5.40a	57.05 ± 2.20c	134.30 ± 5.50b
Supra-optimum	25.62 ± 0.97a	131.23 ± 5.22a	45.14 ± 1.76b	114.09 ± 4.67a
CD (0.05)	0.79	0.91	0.97	4.55
T × Irr	*	*	*	*
Nutrient (Nu)				
1. Control (T_0)	23.55 ± 0.89a	94.95 ± 3.70b	39.03 ± 1.60a	123.16 ± 5.04b
2. RDN through urea (T_1)	29.29 ± 1.11d	123.23 ± 5.05c	47.73 ± 1.86b	134.36 ± 5.37d
3. 75% RDN through urea + 25% RDN through farmyard manure (FYM) (T_2)	32.11 ± 1.31e	135.95 ± 5.57d	55.14 ± 2.15d	135.54 ± 5.56d
4. 75% RDN through urea + 25% RDN through green manure (GM) (T_3)	26.28 ± 0.99c	135.07 ± 5.53d	45.92 ± 1.83b	128.26 ± 5.13c
5. 75% RDN through urea + 25% through biofertilizer (T_4)	29.68 ± 1.15d	174.74 ± 7.16f	50.33 ± 1.91c	131.97 ± 5.41d
6. 75% RDN through urea + 25% RDN through sewage sludge (T_5)	23.35 ± 0.91b	152.79 ± 6.42e	44.65 ± 1.74b	128.45 ± 5.14c
7. 50% RDN as FYM + 25% RDN through biofertilizer + 25% RDN through green manure (T_6)	32.85 ± 1.25e	189.48 ± 7.39 g	61.55 ± 2.46e	134.03 ± 5.63d
8. Blank plot (T_7)	23.72 ± 0.92a	64.92 ± 2.59a	37.05 ± 1.41a	112.22 ± 4.60a
C.D. (0.05)				
T × Nu	*	*	*	*
Irr × Nu	*	*	*	*
T × Irr × Nu	*	*	*	*

Notes: Values of conservation and conventional tillage are mean of respective tillage values across irrigation and nutrient treatments. Similarly, values for irrigation and nutrient treatments are means of respective parameters of the other two. CD represents critical differences and RDN denotes recommended dose of nitrogen. Values for interactions are statistically significant at 5% level. Data were analyzed by one way ANOVA at $p \leq 0.05$ level as determined by Duncan's multiple range test. Different alphabets indicate significant difference between two values.

*Significant at 5% level.

higher soil glucosidase activity as compared to the two (sub-optimum) and five-irrigation regime (supra-optimum), respectively (Table 5). The use of urea as a sole N-source caused a 17% reduction in soil glucosidase activity under two-irrigation regime compared to the five-irrigation regime; whereas, soil glucosidase activity under five-irrigation regime was statistically similar to that under three-irrigation regime. The use of sole organic source of N caused an increase in about 39% in soil glucosidase activity compared to the control. Other plots receiving RDN in various forms also had higher soil glucosidase activity compared to control plots.

3.2. Soil urease activity

A significantly greater soil urease activity (107%) was detected in zero-tillage plots compared to the conventional-tillage plots (Table 4). Among the INM treatments, the highest rate of soil urease activity was recorded for treatments where the N requirement was met through a sole organic source of N (i.e. 189.481 μg N g^{-1} soil h^{-1}), followed by the treatment where 25% RDN was replaced with biofertilizer (i.e. 174.74 μg N g^{-1} soil h^{-1}), which was further followed by the treatment where 25% RDN was replaced with sewage sludge (i.e.152.79 μg N g^{-1} soil h^{-1}). These values showed significantly higher ($p < 0.05$) soil urease activity for treatments where RDN was replaced with biofertilizer and where sole organic source was used as compared to the control plots. For a given nutrient-management practice, the three different water regimes significantly affected the soil urease activity. Soil receiving sole

Table 5. Effect of tillage methods, irrigation, and various fertilizer combinations on glucosidase (μg NPG per g^{-1}) activity in rice crop

	Tillage							
	Conservation tillage				Conventional tillage			
	Irrigation							
Nutrient treatments	Two-irrigation (sub-optimal)	Three-irrigation (optimum)	Five-irrigation (supra-optimal)	Mean	Two-irrigation (sub-optimal)	Three-irrigation (optimum)	Five-irrigation (supra-optimal)	Mean
Control (T_0)	21.36 ± 0.81a	26.81 ± 1.05a	22.27 ± 0.89a	23.48	14.48 ± 0.55a	17.31 ± 0.67a	14.26 ± 0.57b	15.35
RDN through urea (T_1)	29.81 ± 1.19d	34.78 ± 1.32e	34.77 ± 1.39f	33.12	20.75 ± 0.85d	20.46 ± 0.84c	16.66 ± 0.67d	19.29
75% RDN through urea +25% RDN through farm-yard manure (FYM) (T_2)	32.49 ± 1.26f	33.59 ± 1.37d	27.30 ± 1.06b	31.12	23.88 ± 0.97e	22.41 ± 0.87d	15.21 ± 0.60c	20.50
75% RDN through urea + 25% RDN through green manure (GM) (T_3)	30.49 ± 1.19	25.91 ± 1.03a	26.45 ± 1.03b	27.61	20.56 ± 0.78d	19.13 ± 0.76b	12.37 ± 0.48a	17.35
75% RDN through urea + 25% through biofertilizer (T_4)	23.11 ± 0.92	31.72 ± 1.23c	31.88 ± 1.31d	28.91	17.04 ± 0.66b	22.44 ± 0.89d	17.98 ± 0.70e	19.15
75% RDN through urea + 25% RDN through sewage sludge (T_5)	26.34 ± 1.08	29.68 ± 1.19b	34.96 ± 1.36f	30.33	18.06 ± 0.74c	21.10 ± 0.86c	15.11 ± 0.63c	18.09
50% RDN as FYM + 25% RDN through biofertilizer + 25% RDN through green manure (T_6)	35.52 ± 1.42	41.03 ± 1.60f	33.64 ± 1.35e	36.73	28.72 ± 1.18f	26.98 ± 1.05e	20.01 ± 0.80f	25.24
Blank plot (T_7)	28.21 ± 1.10	29.89 ± 1.23b	28.23 ± 1.13c	28.77	18.61 ± 0.76c	17.42 ± 0.68a	15.19 ± 0.61c	17.07
Mean	30.55	31.68	29.94	30.72	20.27	20.91	18.46	19.88
C.D. (0.05)	1. Tillage × Water Regime = 1.21							
	2. Tillage × Nutrient Management = 1.97							
	3. Tillage × Nutrient Management = 2.42							

Notes: CD represents critical difference and RDN denotes recommended dose of nitrogen. Values are mean of the data ($n = 6$) and are statistically significant at $p < 0.05$. Data were analyzed by one way ANOVA at $p < 0.05$. Data followed by the same letter within a row are not significantly different at $p \le 0.05$ level as determined by Duncan's multiple range test. Different alphabets indicate significant difference between two values.

organic source (FYM, Biofertilizer, and GM, i.e. T_6) for the three-irrigation regime recorded 14 and 31% higher soil urease activity compared to two-irrigation regime and five-irrigation regime, respectively (Table 6). The highest urease activity in plots with urea as N-source was observed for the five-irrigation regime (i.e. 207.87 μg N g^{-1} soil h^{-1}), which was 32% higher than that for three-irrigation plots and 41% higher than that for two-irrigation plots. The use of sole organic source of N caused a 100% increase in soil urease activity compared to the control. Other plots having RDN in various forms also had higher soil urease activity compared to control plots.

3.3. Acid phosphatase activity

The soil acid-phosphatase activity was significantly higher (115%) in zero-tillage plots, compared to the conventional-tillage plots (Table 4). Among INM treatments, the highest rate of soil acid-phosphatase activity was recorded in treatments where the N requirement was met through a sole organic source of N (i.e. 61.55 μg PNPP (p-nitrophenyl phosphate) g^{-1} soil h^{-1}), followed by the

Table 6. Effect of tillage methods, water treatments, and various fertilizer combinations on urease (μg N g^{-1} soil h^{-1}) activity in rice crop

	Tillage							
	Conservation tillage				Conventional tillage			
	Irrigation							
Nutrient treatments	Two-irrigation (sub-optimal)	Three-irrigation (optimum)	Five-irrigation (supra-optimal)	Mean	Two-irrigation (sub-optimal)	Three-irrigation (optimum)	Five-irrigation (supra-optimal)	Mean
Control (T_0)	127.60 ± 4.97b	81.67 ± 3.27b	126.06 ± 5.17b	111.78	62.73 ± 2.45b	103.56 ± 4.04e	68.06 ± 2.72a	78.12
RDN through urea (T_1)	147.23 ± 5.89c	157.33 ± 6.45d	207.86 ± 8.11f	170.87	65.36 ± 2.55b	92.76 ± 3.80d	68.60 ± 2.67a	75.58
75% RDN through urea +25% RDN through farmyard manure (FYM) (T_2)	236.23 ± 9.45e	148.96 ± 5.81c	168.06 ± 6.89c	184.42	95.76 ± 3.93d	93.43 ± 3.64d	73.23 ± 2.93b	87.48
75% RDN through urea + 25% RDN through green manure (GM) (T_3)	167.63 ± 6.54d	192.23 ± 7.54e	198.43 ± 7.94e	186.09	76.23 ± 3.05c	82.86 ± 3.39c	93.06 ± 3.63c	84.06
75% RDN through urea + 25% through biofertilizer (T_4)	257.13 ± 10.54f	285.70 ± 1.11g	187.50 ± 7.69d	243.44	110.86 ± 4.32e	72.96 ± 2.99b	134.26 ± 5.37d	106.04
75% RDN through urea + 25% RDN through sewage sludge (T_5)	222.13 ± 9.11d	216.40 ± 8.66f	171.06 ± 7.01c	203.20	104.83 ± 4.29e	110.53 ± 4.31e	91.80 ± 3.76c	102.39
50% RDN as FYM + 25% RDN through biofertilizer + 25% RDN through green manure (T_6)	265.36 ± 10.87g	303.80 ± 12.15h	232.66 ± 9.54g	267.28	132.56 ± 5.17f	52.90 ± 2.06a	149.23 ± 6.12e	111.57
Blank plot (T_7)	95.96 ± 3.74a	67.70 ± 2.78a	66.36 ± 2.65a	76.68	48.10 ± 1.88a	48.06 ± 1.97a	63.26 ± 2.53a	53.15
Mean	189.91	181.73	169.76	180.47	87.06	82.14	92.69	87.69
C.D. (0.05)	1. Tillage × Water Regime = 1.29							
	2. Tillage × Nutrient Management = 2.12							
	3. Tillage × Nutrient Management = 2.59							

Notes: RDN denotes recommended dose of nitrogen and CD denotes critical difference. Values are mean of the data (n = 6) and are statistically significant at $p < 0.05$. Data were analyzed by one way ANOVA at $p < 0.05$. Data followed by the same letter within a row are not significantly different at $p \leq 0.05$ level as determined by Duncan's multiple range test. Different alphabets indicate significant difference between two values.

treatment where 25% RDN has been replaced with FYM (i.e. 55.14 µg PNPP g^{-1} soil h^{-1}), which is further followed by the treatment where 25% RDN was replaced with biofertilizer (i.e. 50.33 µg PNPP g^{-1} soil h^{-1}). These treatments showed significantly ($p < 0.05$) higher soil acid-phosphatase activity compared to the control. For any given nutrient-management practice, the three different irrigation regimes significantly affected the soil acid-phosphatase activity. Soil receiving N from a sole organic source in three-irrigation regime recorded 26 and 32% higher soil acid phosphatase activity compared to two- and five-irrigation regimes, respectively (Table 7). The use of urea as a sole N-source decreased soil acid-phosphatase activity under two- and five-irrigation treatments by 45 and 50%, respectively, compared to three-irrigation treatment.

3.4. Alkaline phosphatase activity

For rice crop, a significantly greater soil alkaline phosphatase activity (105%) was noted in zero-tillage plots compared to conventional-tillage plots (Table 4). Among the INM treatments, the highest rate of soil alkaline-phosphatase activity was recorded for the treatment where 25% N requirement was met through FYM of N (i.e. 135.54 µg PNPP g^{-1} soil h^{-1} soil), followed by the treatment where urea was used (i.e.134.36 µg PNPP g^{-1} soil h^{-1} soil), which was further followed by the treatment where whole organic source of N was used as RDN (i.e.134.03 µg PNPP g^{-1} soil h^{-1} soil). Significantly ($p < 0.05$) higher soil alkaline-phosphatase activity in treatments with organic amendments was detected

Table 7. Effect of tillage methods, water treatments, and various fertilizer combinations on acid phosphatase (µg PNPP g^{-1} soil h^{-1}) activity in rice crop

	Tillage							
	Conservation tillage				Conventional tillage			
	Irrigation							
Nutrient treatments	Two-irrigation(sub-optimal)	Three-irrigation (optimum)	Five-irrigation (supra-optimal)	Mean	Two-irrigation(sub-optimal)	Three-irrigation (optimum)	Five-irrigation (supra-optimal)	Mean
Control (T_0)	47.62 ± 1.81b	60.67 ± 2.43a	51.34 ± 2.00a	53.21	20.26 ± 0.83b	29.55 ± 1.15a	24.73 ± 1.01a	24.85
RDN through urea (T_1)	57.05 ± 2.28c	82.61 ± 3.39d	55.22 ± 2.15b	64.96	24.55 ± 0.93c	39.49 ± 1.62d	27.43 ± 1.04b	30.49
75% RDN through urea +25% RDN through farm-yard manure (FYM) (T_2)	70.99 ± 2.91d	85.81 ± 3.43d	68.90 ± 2.82d	75.24	29.15 ± 1.14d	43.83 ± 1.71e	32.17 ± 1.32c	35.05
75% RDN through urea + 25% RDN through green manure (GM) (T_3)	57.62 ± 2.25c	71.57 ± 2.93b	59.38 ± 2.49c	62.86	23.47 ± 0.91c	31.21 ± 1.28b	32.30 ± 1.29c	28.99
75% RDN through urea + 25% through biofertilizer (T_4)	60.55 ± 2.54c	78.91 ± 3.31c	64.28 ± 2.57d	67.91	29.30 ± 1.20d	34.53 ± 1.38c	34.44 ± 1.34d	32.75
75% RDN through urea + 25% RDN through sewage sludge (T_5)	49.88 ± 2.09b	75.63 ± 3.01c	56.63 ± 2.21b	60.72	21.62 ± 0.82b	34.87 ± 1.36c	29.24 ± 1.19b	28.58
50% RDN as FYM + 25% RDN through biofertilizer + 25% RDN through green manure (T_6)	78.91 ± 3.31d	99.43 ± 4.17e	75.39 ± 3.09e	84.57	32.37 ± 1.26e	46.05 ± 1.75f	37.19 ± 1.45e	38.54
Blank plot (T_7)	32.89 ± 1.28a	69.03 ± 2.83b	51.29 ± 2.10a	51.07	16.93 ± 0.67a	29.67 ± 1.16a	22.28 ± 0.85a	22.96
Mean	56.94	77.96	60.31	65.07	24.71	36.15	29.97	30.28
C.D. (0.05)	1. Tillage × Water Regime = 1.38							
	2. Tillage × Nutrient Management = 2.26							
	3. Tillage × Nutrient Management = 2.27							

Notes: RDN denotes recommended dose of nitrogen and CD denotes critical difference. Values are mean of the data ($n = 6$) and are statistically significant at $p < 0.05$. Data were analyzed by one way ANOVA at $p < 0.05$. Data followed by the same letter within a row are not significantly different at $p \le 0.05$ level as determined by Duncan's multiple range test. Different alphabets indicate significant difference between two values.

Table 8. Effect of tillage methods, water treatments, and various fertilizer combinations on alkaline phosphatase (μg PNPP g^{-1} soil h^{-1}) activity in rice crop

	Tillage							
	Conservation tillage				Conventional tillage			
	Irrigation							
Nutrient treatments	**Two-irrigation (sub-optimal)**	**Three-irrigation (optimum)**	**Five-irrigation (supra-optimal)**	**Mean**	**Two-irrigation (sub-optimal)**	**Three-irrigation (optimum)**	**Five-irrigation (supra-optimal)**	**Mean**
Control (T_0)	171.10 ± 7.01a	182.16 ± 7.28b	145.76 ± 5.54b	166.34	84.33 ± 3.20a	88.73 ± 3.46b	66.86 ± 2.61a	79.97
RDN through urea (T_1)	180.73 ± 7.23b	194.36 ± 7.77c	156.23 ± 6.09b	177.11	92.40 ± 3.79d	104.70 ± 3.98d	77.73 ± 3.03c	91.61
75% RDN through urea +25% RDN through farm-yard manure (FYM) (T_2)	179.36 ± 7.17b	194.20 ± 7.96c	158.13 ± 6.33b	177.23	92.40 ± 3.69d	105.40 ± 4.11d	83.76 ± 3.18d	93.85
75% RDN through urea + 25% RDN through green manure (GM) (T_3)	172.46 ± 7.07a	186.63 ± 7.83b	155.93 ± 6.39b	171.67	89.23 ± 3.39b	87.36 ± 3.32b	77.93 ± 2.96c	84.84
75% RDN through urea + 25% through biofertilizer (T_4)	181.26 ± 7.06b	192.76 ± 7.32c	162.36 ± 6.49c	178.80	86.86 ± 3.30d	93.43 ± 3.55c	75.13 ± 2.93c	85.14
75% RDN through urea + 25% RDN through sewage sludge (T_5)	176.7 ± 07.24b	190.00 ± 7.6c	158.86 ± 6.67b	175.18	83.83 ± 3.18c	90.70 ± 3.45b	70.63 ± 2.96b	81.72
50% RDN as FYM + 25% RDN through biofertil-izer + 25% RDN through green manure (T_6)	183.56 ± 7.71b	193.00 ± 8.10c	168.30 ± 7.06d	181.62	88.30 ± 3.44b	89.50 ± 3.76b	81.51 ± 3.42d	86.43
Blank plot (T_7)	168.00 ± 7.05a	166.80 ± 6.84a	124.26 ± 5.09a	153.02	83.10 ± 3.40a	69.10 ± 2.76a	62.06 ± 2.60a	71.42
Mean	176.65	187.49	158.73	172.62	87.50	91.12	74.45	84.35
C.D. (0.05)	1. Tillage × Water Regime = 6.44							
	2. Tillage × Nutrient Management = 10.52							
	3. Tillage × Nutrient Management = 12.89							

Notes: RDN denotes recommended dose of nitrogen and CD denotes critical difference. Values are mean of the data (n = 6) and are statistically significant at $p < 0.05$. Data analyzed by one way ANOVA at $p < 0.05$. Data followed by the same letter within a row are not significantly different at $p \leq 0.05$ level as determined by Duncan's multiple range test. Different alphabets indicate significant difference between two values.

than in the control plots. For any given nutrient-management practice, the three different water regimes significantly increased the soil alkaline-phosphatase activity. Soil receiving RDN as urea in the three-irrigation treatment recorded 8 and 24% higher soil alkaline-phosphatase activity compared to two- and five-irrigation treatments, respectively (Table 8). The use of sole organic source for N with three irrigation regimes gave statistically similar result as that from the plots where urea was used as the source of RDN. The use of RDN as urea caused a 9% increase compared to the control. Other plots receiving RDN in various forms also had higher soil alkaline-phosphatase activity compared to control plots.

3.5. Effect of resource management practices on soil microbial activities (soil respiration, dehydrogenase, and soil microbial biomass carbon) and grain number of rice

The resource management practices (RMPs) such as conservation tillage, water, and nutrient management, had a significant positive effect on soil microbial activities such as SR, SMBC, and DHA. All parameters of soil microbial activities registered a significant increase, i.e. SR (36.46%), SMBC (95.38%), and DHA (74.34%), in plots where sole organic source was used for N, along with conservation tillage and three irrigations compared to the plots where RDN as urea was used as a source of N (Table 9). Similarly, conventional-tillage plots showed a reduction in SR, SMBC, and DHA in relation to conservation-tillage plots across all three irrigation regimes and nutrient-management practices. In general,

Table 9. Effect of various INM practices on SR, SMBC, soil DHA, and metabolic quotient of soil after rice cultivation

Treatments/N-source	Soil respiration (mg CO_2 (100 g)$^{-1}$soil h^{-1})	Soil microbial biomass carbon (μgMBC g^{-1}soil)	Soil dehydrogenase activity (μg TPFg^{-1} soil per h^{-1})	Metabolic quotient i.e. qCO_2
T_0 (No external fertilizer)	0.96 ± 0.03a	81.17 ± 3.40a	1.13 ± 0.05b	11.83 ± 0.45d
T_1 (RDN through urea)	1.17 ± 0.05c	101.32 ± 4.04c	1.82 ± 0.07d	11.55 ± 0.45d
T2 (75% RDN through urea + 25% RDN through farmyard manure (FYM))	1.16 ± 0.05c	116.45 ± 4.89d	1.86 ± 0.08d	9.96 ± 0.39b
T_3 (75% RDN through urea + 25% RDN through green manure (GM))	1.02 ± 0.04b	98.10 ± 4.12b	1.21 ± 0.05c	10.39 ± 0.40c
T_4 (75% RDN through urea + 25% through biofertilizer)	1.24 ± 0.05d	134.06 ± 5.63e	1.80 ± 0.07d	9.25 ± 0.38b
T_5 (75% RDN through urea + 25% RDN through sewage sludge)	1.03 ± 0.04b	98.94 ± 4.06b	1.22 ± 0.05c	10.41 ± 0.44c
T_6 (50% RDN as FYM + 25% RDN through biofertilizer + 25% RDN through green manure)	1.31 ± 0.05e	158.59 ± 6.66f	1.97 ± 0.08e	8.26 ± 0.35a
T_7 (Blank plot)	0.98 ± 0.03a	84.43 ± 3.46a	1.09 ± 0.04a	11.61 ± 0.46d

Notes: T_1–T_7 have their usual meanings as given in Table 3. The values for T_1–T_7 are obtained by taking mean of all the values of a nutrients treatment (say T_1, T_2 etc.) in all the three water regimes. (i.e. two-, three-, and five-irrigations) for both conservation tillage and conventional tillage for SR, SMBC, and soil DHA. This was done to see the individual effect of a particular nutrient treatment in both the tillage systems. Data followed by the same letter within a row are not significantly different at $p \le 0.05$ level as determined by Duncan's multiple range test. Different alphabets indicate significant difference between two values.

among the irrigation practices, the three-irrigation treatment showed higher enzymatic activities than did two- and five-irrigation treatment, in both the tillage systems. Among the nutrient treatments, the sole organic source treatment in conjunction with conservation tillage and three-irrigation regime showed significantly higher microbial activities compared with other INM treatments.

The increase in grain number was observed following the use of conservation-tillage practices (Table 10). The grain number increased significantly when 25% biofertilizer had been replaced with RDN or when sole organic source of N was used with conservation tillage.

4. Discussion

The tillage (i.e. no-tillage) and nutrient management have brought about increase in soil microbial and enzymatic activities viz. soil glucosidase, urease, acid and alkaline phosphatase (Tables 1, 2, 4 and 5). The soil enzymatic activities have shown positive synergistic effect of the RMPs studied i.e. conservation tillage with three-irrigations (at the gap of 20-days). The organic nutrient forms affect the rhizospheric microbial properties in different tillage and water regimes (Singh et al., 2009).

Our study has shown an improvement in glucosidase enzyme activity with tillage, water, and nutrient resource management, which subsequently resulted in higher available C in the soil and improved the microbial population in soil under rice cultivation. The role of glucosidase enzyme during carbon (C) cycle has been suggested by Deng and Tabatabai (1996). The increased soil glucosidase activity in conservation tillage system might be attributable to increased SR and soil organic matter (SOM) while in the conventional tillage system, soil disturbance results in the rapid rate of plant residue decomposition which exacerbates the mineralization of C and N in the soil which further led to loss of organic matter and enzyme activity of soil. This view is supported by the idea forwarded by Balosa, Kanashiro, Filho, Andrade, and Dick (2004) and Mohanty, Painuli, Misra, and Ghosh (2007). Thus, it appears that glucosidase enzyme activity of C-cycle increases with the use of

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Table 10. Effect of tillage methods, water treatments, and various fertilizer combinations on grain number in rice

Treatments/N-source	Grain number during conservation tillage	Grain number during conventional tillage
T_0 (No external fertilizer)	82.56 ± 3.22a	73.67 ± 3.02a
T_1(RDN through urea)	91.67 ± 3.57b	79.11 ± 3.01b
T_2 (75% RDN through urea + 25% RDN through farmyard manure (FYM))	93.56 ± 3.74b	79.11 ± 3.08b
T_3 (75% RDN through urea + 25% RDN through green manure (GM))	95.11 ± 3.89c	79.22 ± 3.32b
T_4 (75% RDN through urea + 25% through biofertilizer)	98.22 ± 4.13d	83.34 ± 3.42c
T_5 (75% RDN through urea + 25% RDN through sewage sludge)	90.89 ± 3.82b	77.22 ± 3.24b
T_6 (50% RDN as FYM + 25% RDN through biofertilizer + 25% RDN through green manure)	107.00 ± 4.39e	85.67 ± 3.59c

Notes: T_1–T_7 have their usual meanings as given in Table 3. The values for T_1–T_7 are obtained by taking mean of all the values of a nutrients treatment (say T_1, T_2 etc.) in all the three water regimes. (i.e. two-, three-, and five-irrigations) for both conservation tillage and conventional tillage. This was done to see the individual effect of a particular nutrient treatment in both the tillage systems. Data followed by the same letter within a row are not significantly different at $p \leq 0.05$ level as determined by Duncan's multiple range test. Different alphabets indicate significant difference between two values.

resource management and organic nutrients which subsequently results in high available C in the soil and improves the microbial population in the soil. Similar results have been reported by Zhang et al. (2010).

Tillage practices have been shown to affect soil nutrient content, enzymatic activity, and microbial activity under the Indian sandy clay loam soil (Mathers & Nash, 2009). The agroecosystem functioning and global element cycling has been affected by microbial communities of rhizosphere of plants. Thus, the rhizosphere of plants contributes significantly to biogeochemical cycles (circulation of elements like C, N, P, S etc.) in biosphere. It has been reported that no-tillage (i.e. conservation tillage) practices increases availability of soil enzymes (like acid phosphatase, amylase, cellulase, urease, etc.) in rhizosphere and hence nutrient cycling (Davis, Parton, Dohleman, & Smith, 2010). The urease activity was higher in the conservation tillage fields across all the nutrient treatments as compared to the conventional tillage fields (Table 6). Individual effects of resource optimization in improving soil urease activity and sustained growth of plant have been reported by previous workers (Davis et al., 2010; Mathers & Nash, 2009). Our results emphasized that conservation tillage and three-irrigations enhanced the soil urease activity, synergistically. The soil urease activity increased with reduced tillage, optimal (three-) irrigations and mixed use of chemical and organic nutrients as shown in Tables 4 and 6. This might be attributable to improvement in intracellular and extracellular soil urease activity (Qin, Hu, Wang, Li, & He, 2010).

The present day agriculture is dependent on chemical (i.e. N, P, K) fertilizers and energy intensive processes (Bosede, 2010). It has been established that chemical fertilizers cause many problems like soil alkalinity, acidity, yield stagnation, etc., and are the major source of environmental pollution. So, nowadays, emphasis of research has been shifted toward exploring the alternative organic options for inorganic N, P, K fertilizers (Mahajan & Gupta, 2009). Our work highlighted that INM practices could reduce dependence on chemical fertilizers, irrigation, and tillage. Further, we observed that integrated use of conservation tillage, three-irrigation, and sole organic source resulted in a 20% increase in acid phosphatase activity compared to urea treatment while the increase was 60.89% compared to the control when urea was used as RDN. Our results showed that acid-phosphatase activity was positively related to the integrated use of conservation tillage, three-irrigations, and various combinations of organic and inorganic fertilizers (Table 8). The soil acid-phosphatase activity was higher for the conservation-tillage treatment compared to the conventional-tillage treatment across all the nutrient treatments and irrigation regimes. Roldan, Garcia, and Alguacil (2005) have reported that no-tilled soils had increased values of acid phosphatase activity as compared to the tilled soils. The increased acid phosphatase activity might be attributable to increased organic matter which further led to phosphorus (P) stress. The P-stress stimulated plant roots to secrete acid phosphatase for their hydrolyzation (Balemi & Negisho, 2012).

Soil alkaline-phosphatase activity was significantly higher in case of conservation-tillage treatment for the three-irrigation regime across various nutrient sources (T_1–T_6) as compared to the conventional-tillage treatment and other two irrigation regimes (two- and five-irrigation regime) (Table 8). These results implied that conservation tillage, optimum (three-) irrigations, and nutrient-management practices improve soil alkaline phosphatase activity. The observed increase in alkaline-phosphatase activity might be due to increased contents of SOM, total N, P, K, ammonia ion (NH_3^+) and available P, K which further led to increased activity of phosphatase (alkaline) enzyme (Li et al., 2010). This suggests a relationship between conservation tillage, optimum (i.e. three-) irrigations, and organic fertilizers with alkaline phosphatase activity. Similar, results in cereals have been reported by Mikanová, Javůrek, Šimon, Friedlová, and Vach (2009).

The major soil microbiological parameters such as SR and soil microbial biomass showed an increase, along with an increase in the organic content of the fertilizer mixture (Table 9). Our study showed that the low qCO_2 values during the INM practices correspond with an increased microbial activity which is directly related to soil fertility. Thus, the decreased qCO_2 with increase in the organic content of the fertilizer (Table 9) suggested an increase in the microbial efficiency of soil as both parameters (i.e. qCO_2 and microbial efficiency) has been found to be inversely related (Hu & Cao, 2007). The increase in microbial content and decrease in qCO_2 indicated a shift toward stability in the *Leucaena leucocephala* and *Arachis hypogaea* system (Balota & Chaves, 2011). In our study, the SMBC, SR, and DHA increased and qCO_2 values decreased with an increase in organic content in the fertilizer mixture, which indicated an increase in the fertility of soil and thus increase in yield of rice crop (Table 10). The variations on qCO_2 values for various nutrient treatments in our experiment could be due to differences in the accessibility of C substrates to the micro-organisms, changes in the microbial metabolic rates, and changes in the microbial community composition and their physiological standards (Islam & Weil, 2000).

The water has been a precious resource for agriculture. But excessive use of water has created a condition of shortage. The excessive water can harm soil microbes and produces anaerobic conditions like hypoxia (a condition of oxygen deficiency). The reproductive growth of plant is negatively affected by hypoxic conditions. The hypoxic conditions also reduces yield of rice plant (Prasad & Nagarajan, 2004). Therefore, optimization is essential for higher enzymatic activities which may further increase soil microbial activities and yield of plant (Singh, Dahiya, & Jaiwal, 2006). We have also observed that three irrigations enhance soil enzymatic activities (Table 5) compared to the two- and five-irrigation treatments.

Our results indicate INM practices, especially, when whole organic source treatment replaces recommended dose of nutrients or when 25% RDN is replaced by biofertilizer or when 25% RDN is replaced by FYM along with conservation/reduced tillage and water management maintains high soil glucosidase, urease, and phosphatase which are essential for C, N, and P circulation in soil (Tables 4–9) during rice cultivation. Further, microbial activity of soil and yield of rice plants (Table 10) have also been increased with the use of RMPs. Similar results in cereals have been reported by Mikanová et al. (2009).

5. Conclusions

Conservation tillage, three-irrigation regime, and nutrient treatments, where 50% FYM + 25% GM + 25% biofertilizer had been used as a replacement for RDN (as urea) or where urea was replaced with 25% FYM or 25% GM or 25% biofertilizer or 25% sewage sludge, improved activities of important soil enzymes (glucosidase, urease, and phosphatase), and overall microbial activity, e.g. SR, SMBC, and DHA, following rice cultivation. The improvement in enzymatic activity could lead to improvement in mobility of nutrients in the soil.

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