Oryza **Vol. 56 No. 3, 2019 (305-311)**
DOI https://doi.org/10.35709/ory.2019.56.3.6

Influence of long-term fertilization on soil microbial biomass and dehydrogenase activity in relation to crop productivity in an acid *Inceptisols*

Debasis Purohit, Mitali Mandal*, Avisek Dash, Kumbha Karna Rout, Narayan Panda and Muneswar Singh

Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India

****Corresponding author e-mail: mitalimandal83@gmail.com***

Received : 2 May 2019 Accepted: 24 September 2019 Published : 30 September 2019

ABSTRACT

*An effective approach for improving nutrient use efficiency and crop productivity simultaneously through exploitation of biological potential for efficient acquisition and utilization of nutrients by crops is very much needed in this current era. Thus, an attempt is made here to investigate the impact of long term fertilization in the soil ecology in rice-rice cropping system in post kharif - 2015 in flooded tropical rice (Oryza sativa L.) in an acidic sandy soil. The experiment was laid out in a randomized block design with quadruplicated treatments. Soil samples at different growth stages of rice were collected from long term fertilizer experiment.The studied long-term manured treatments included 100 % N, 100% NP, 100 % NPK, 150 % NPK and 100 % NPK+FYM (5 t ha^{-1}) and an unmanured control. Soil fertility status like SOC content and other available nutrient content has decreased continuously towards the crop growth period. Comparing the results of different treatments, it was found that the application of 100% NPK + FYM exhibited highest nutrient content in soils. With regards to microbial properties it was also observed that the amount of microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) showed highest accumulation in 100 % NPK + FYM at maximum tillering stage of the rice. The results further reveal that dehydrogenase activity was maximum at panicle initiation stage and thereafter it decreases. Soil organic carbon content, MBC, MBN and dehydrogenase activity were significantly correlated with each other. Significant correlations were observed between rice yield and MBC at maturity stage(R^2 = 0.94**) and panicle initiation stage(R^2 = 0.92**) and available nitrogen content at maturity stage(R^2 = 0.91**).*

Key words: *Long term fertiliser treatment, Rice- Rice,MBC, MBN and soil fertility*

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food source for almost half of the world population (Rice Almanac, 2002). For feeding the growing population in a sustainable manner it is an urgent need to increase the productivity of existing rice cropping system. The future of the food security system, not only in India but the whole South East Asia, depends upon the ability to achieve a trend of growth towards productivity and profitability of rice farming system on an ecologically sustainable basis (Swaminathan, 1993). For over a decade, yield of rice-rice cropping system have either stagnated or declined. The most important reason is a decline in factor productivity resulting from depletion of soil fertility. The system commonly shows signs of fatigue and is no longer exhibiting increased production with higher input use based on the current pattern. Even with current generalized recommended rates of fertilization for this system, a negative balance of the primary nutrients exists (Shukla et al., 2005). The practice of adopting a cereal-cereal cropping system on the same piece of land over years has led to soil fertility deterioration and questions are being raised about its sustainability.

Soil microorganisms are key players in terrestrial agroecosystems, involved in soil organic matter decomposition, nutrient cycling, bioremediation of pollutants and sustaining soil productivity (Luo et al., 2015). Agricultural practices have significant influence on the soil microbial activities and health of soils. Continuous application of fertilizers has changed the composition and functions of soil microorganisms (Dong et al., 2014). Activity of soil enzymes is widely used as an indicator of soil quality. They play crucial role in soil organic matter (SOM) decomposition and nutrient cycling. Dehydrogenase activity (DHA) is a generalized indicator of soil catabolic activity reflective of carbon cycling. Arylsulfatase and urease are involved in sulfur (S) and nitrogen (N) cycles respectively (Das and Varma, 2011).

Long-term studies are essential to understand the effect of different management practices on soil and developing location specific sustainable crop production systems. Since microbial processes are dynamic, patterns of temporal fluctuation during crop growth are of great importance in relation to the nutrient supplying capacity of the ecosystem and the crop demands. Very little information is still now available on the influence of long term fertilization and cropping pattern on soil microbial indices of soil quality *e.g.*, MBC, MBN, DHA in rice-rice ecosystems and how they relate to crop and nutrient management practices. Therefore, the present investigation was undertaken to evaluate the impact of long-term application of mineral fertilizers and farm yard manure on soil microbial activities, and their relationships with crop yields in humid tropical India.

MATERIALS AND METHODS

The ongoing long-term fertilizer experiment of All India Coordinated Research Project (AICRP) of ICAR at OUAT, Bhubaneswar, India (20°17' N, 85°49' E and 30 m above mean sea level) initiated during 2005-06 was selected for this study. The location of the experimental site is characterized as sub humid subtropical climate with dry season from October to June and wet season from July to September. The soil of the experimental site was sandy loam in texture, acidic (pH 5.8) and udic ustochrept type. Rice cultivar Swarna (MTU-7029) was grown under flooded condition in *kharif* season and Lalat (IET-9947) in *rabi* of every year. Seven treatments *viz*., 100% N, 100% NP, 100% NPK at 80:40:40 kg ha^{-1} of N : P_2O_5 : K_2O in the form of DAP, urea and MOP; 150% NPK; 100% NPK+ FYM; FYM at 5 t ha^{-1} and an unfertilized control were evaluated for the study. Nitrogen was applied in three splits *i.e.*, 25% as basal, 50% at 18 days after transplanting and 25% at panicle initiation stage. Total P was applied as basal and K was applied 50% as basal and 50 % at panicle initiation stage. Rice plants (21 days old seedlings of cv. MTU-7029, Swarna) were transplanted @ 2-3 seedlings/hill in third week of July. All the field plots remained continuously flooded to a water depth of 3 cm during the entire period of crop growth and were drained 10 days before harvest. Necessary intercultural, water management and plant protection measures were undertaken in general until the crop was matured for harvesting. The experiment was laid out in randomized block design (RBD) and replicated 4 times out of which 3 replications are taken for laboratory analysis.

In this study, soil samples were collected from the surface layer (0-15 cm) of each plot at three rice growth stages *viz*., maximum tillering stage (24 days after transplanting), panicle initiation stage (52 days after transplanting) and maturity stage (100 days after transplanting) in *kharif* season during 2015. Five representative soil samples (in between plant rows) from each replicated plot were collected randomly from 0-15 cm depth with the help of sample tube and then mixed to make a composite sample. After sampling, excessive water was drained off on the ground. Visible root fragments and stones were removed manually. After hand crushing, field moist soil samples were stored at 4^0C and were used afresh for estimation of soil microbial biomass carbon, microbial biomass nitrogen and dehydrogenase activity. A second set of soil samples were air dried and passed through a 2 mm sieve for determination of soil physico-chemical and chemical properties. Another triplicate soil samples were used for soil moisture content. Soil moisture content of individual sample was determined gravimetrically in 10 g portion after drying at 105^0C for 24 hours. Soil pH was determined with a glass electrode pH meter (Jackson, 1973). Available N was determined by Kjeldahl method (Subbiah and Asija, 1956). The soil organic carbon (SOC) was determined by dichromate oxidation (Walkley and Black, 1934). The MBC was determined by fumigation extraction method (Vance et al., 1987). Dehydrogenase was determined by monitoring the rate of production of triphenyl formazan (Tabatabai, 1982). All the data were subjected to statistical analysis with software SPSS (Kirkpatrick and Feeney, 2005) for significant differences between treatments using analysis of variance (ANOVA) at 5% significance level and correlation between microbial properties and soil available nutrient contents were worked out.

RESULTS AND DISCUSSION

Effect of long-term manuring on the changes of SOC content at different growth stages of rice

Experimental results reveal that SOC content was significantly affected by fertilizer treatments, stages of rice growth and their respective interactions (Table 1). Mean seasonal SOC content ranged from 4.4 g kg^{-1} in control to 12.2 g kg^{-1} in plots receiving balanced fertilization along with organic manure in soil. Organic amendment in combination with inorganic fertilizers enhanced SOC content with a significant loss in soil C content in unamended control (Purokayastha et al., 2008; Nayak et al., 2012). Fertilization has varying effects on SOC Content in soils. The results showed that the application of 100% NPK+ FYM was found better than rest of the treatments under investigation. Imbalanced fertilization did not differ significantly in their SOC content. Super optimal dose of NPK recorded 28% higher SOC over balanced fertilization. Among the different rice crop growth stages, the maximum tillering stage of rice crop registered highest SOC content (9.8 g kg^{-1}) followed by panicle initiation stage (8.2 g kg^{-1}) and maturity stage 5.2 g kg^{-1}. The increase in SOC content at maximum tillering stage could be due to higher production of root exudates in comparison to the maturity stage (Aulakh et al., 2001).

Effect of long-term manuring on the changes in available soil nitrogen content at different growth stages of rice

Available nitrogen content in soil samples varied significantly due to long-term fertilizer treatments, stages of rice growth and their interactions (Table 2). In general, net available nitrogen content significantly increased by fertilization. Mean seasonal nitrogen content varied from 162.87 kg ha^{-1} in control to 260.34 Kg ha^{-1} in 100% NPK+ FYM treatment. Application of manures along with balanced fertilization led to enrichment in the soil N pool and increased the efficiency of organic fertilizer by releasing higher mineral N (Res and Castle, 2002; Kumar et al., 2018). Imbalanced fertilization without nitrogen source differed significantly with nitrogen source but there was no significant variation between only nitrogen source and addition of phosphorus source to the nitrogen. 150 % NPK showed 17 % higher nitrogen content over balanced fertilization. Available nitrogen content was found to be maximum at maximum tillering stage and thereafter gradually decreased up to maturity stage which may be due to highest N availability at early rice growth stages due to mineralization of N from basal fertilizer application and latter stage decreased due to decreased labile organic matter and microbial activity

Table 1. Effect of long-term manuring on the changes in soil organic carbon (g/kg) at different growth stages of rice.

Treatment	Crop growth stages			Grand mean
	MT	PI	MA	
100 % NPK	8.2	6.3	4.4	6.3
150% NPK	9.8	9.2	5.4	8.1
100 % NPK +FYM	16.8	13.9	6.1	12.2
100 % N	7.5	5.3	4.7	5.8
100 % NP	8.3	7.7	5.2	7.1
Control	4.9	4.4	3.9	4.4
Mean	9.86	8.27	5.20	7.78

LSD (P=0.5): T: 0.49; CGS: 0.24; Tx CGS: 0.85

MT-Maximum tillering, PI-Panicle initiation, MA-Maturity

Table 2. Effect of long term manuring on the changes of available nitrogen (kg/ha) in soil at different growth stages of rice.

Treatment	Crop growth stages			Grand mean
	MT	PI	MA	
100 % NPK	216.82	197.97	189.23	201.34
150% NPK	250.59	236.85	220.73	236.06
100 % NPK +FYM	279.50	269.61	231.92	260.34
100 % N	203.92	183.92	177.00	188.28
100 % NP	210.53	193.31	181.25	195.03
Control	178.88	164.09	145.63	162.87
Mean	234.88	219.65	198.74	217.76

LSD (P=0.5): T: 20.7; CGS: 1.03; Tx CGS: 3.59

MT- Maximum tillering, PI- Panicle initiation, MA- Maturity, (Ghosh and Kashyap, 2003).

Effect of long-term manuring on the changes in microbial biomass carbon content at different growth stages of rice

Perusal of results (Table 3) revealed that the MBC content was highest in plots receiving both organic manure and inorganic fertilizers and lowest in unamended control plots. Amendment of organic material input leads to more organic carbon to the soil, which could stimulate the microbial growth and activity (Dhull et al., 2004; Panda et al., 2018). This results corroborated with the findings of Mandal et al. (2018) There was significant variation in MBC content in balanced (100 % NPK) and imbalanced fertilization(100 % N or 100 % NP). With the addition of extra 50 % NPK in the balanced fertilization did not significantly increase MBC content (146.77 µg g^{-1} of dry soil) over the balanced fertilization (142.95 µg g^{-1} of dry soil). But addition of organic manure increase 29 % more soil MBC over 100% NPK treatment. MBC was influenced by the crop growth stages and maximum value was obtained at maximum tillering stage irrespective of treatments and declined thereafter which might be due to the less root exudation coupled with the soil drainage at rice maturity (Aulakh et al., 2001).

Effectof long-term manuring on the changes in microbial biomass nitrogen content at different growth stages of rice

The appraisal of the results of the present study (Table 4) demonstrated that MBN was significantly affected by long-term fertilization, stages of crop growth and their interactions. Mean seasonal MBN content in soil ranged from 23.75 µg g^{-1} dry soil in control and 107.59 µg g^{-1} dry soil in 100 % NPK + FYM in soil. Fertilization greatly affected MBN content in soil. Unfertilized control plot showed significantly lower MBN content than other treatments in all the growth stages of rice due to low SOC content (Srinivasarao et al., 2018). Balanced fertilization along with FYM produced highest MBN content in the crop development stages as it supplies organic substances and nutrients in readily available form that triggers microbial population (Ge et al., 2009). Super-optimal dose of NPK exhibited more MBN content than balanced fertilization irrespective crop growth stages. MBN content decreased with the development of rice growth which may be due to carbon limitation in the later stage (Mandal et al., 2007). The higher magnitude was found at maximum tillering stage in all the treatments.

Table 4. Effect of long-term manuring on the changes in microbial biomass nitrogen (µg g^{-1} of dry soil) at different growth stages of rice.

Treatment	Crop growth stages			Grand
	MT	PI	MA	mean
100 % NPK	74.54	57.34	38.87	56.91
150 % NPK	100.39	75.88	53.20	76.49
100 % NPK + FYM	128.94	109.07	84.78	107.59
100 % N	63.17	50.09	35.34	49.53
100 % NP	67.31	60.04	43.85	57.07
Control	31.60	24.27	15.38	23.75
Mean	84.68	68.78	52.22	68.56

LSD (P=0.5): T: 1.75; CGS: 0.88; Tx CGS: 3.04

MT- Maximum tillering, PI- Panicle initiation, MA- Maturity

Table 3. Effect of long-term manuring on the changes of microbial biomass carbon (µg g^{-1} of dry soil)at different growth stages of rice.

Treatment	Crop growth stages			Grand
	MT	PI	MA	mean
100 % NPK	142.95	108.99	94.03	115.41
150 % NPK	146.77	128.24	112.69	129.23
100 % NPK +FYM	183.82	160.69	142.85	162.45
100 % N	120.08	92.80	79.96	97.61
100 % NP	131.42	100.22	88.89	106.84
Control	90.51	60.35	46.35	65.74
Mean	144.28	121.59	106.83	124.23

LSD (P=0.5): T: 4.46; CGS: 2.23; Tx CGS: 7.72

MT- Maximum tillering, PI- Panicle initiation, MA- Maturity

Table 5. Effect of long term manuring on the changes in dehydrogenase activity (µg of TPF/ g of soil / 24 hours) at different growth stages of rice.

Treatment	Crop growth stages			Grand
	MT	PI	MA	mean
100 % NPK	25.13	32.97	26.18	28.10
150 % NPK	39.12	51.00	31.39	40.50
100 % NPK + FYM	55.97	59.23	45.82	53.67
100 % N	7.96	11.82	6.71	8.83
100 % NP	13.54	24.10	11.54	16.39
Control	4.83	10.51	3.72	6.35
Mean	23.74	32.12	20.96	25.61

LSD (P=0.5): T: 1.00; CGS: 0.50; Tx CGS: 1.41

MT- Maximum tillering, PI- Panicle initiation, MA- Maturity

Effect of long term manuring on the changes in dehydrogenase activity at different growth stages of rice

It is evident from the experimental results presented in the Table 5 that dehydrogenase activities were strongly influenced by the long term manuring and inorganic fertilizers as well as the interactive effect of crop growth stages. Dehydrogenase activity increased soon after flooding with the maximum activity being recorded at the panicle initiation stage and declined sharply at maturity stage. The seasonal dehydrogenase enzyme activity was recorded lowest (6.35 µg of TPF g^{-1} dry soil per 24 hours) in control and highest (53.67 µg of TPF g^{-1} dry soil per 24 hours) in 100 % NPK + FYM . Highest enzyme activity in the plot receiving both organic manure and inorganic fertilizers is due to improved organic matter and MBC status of soils, that is directly proportional to higher dehydrogenase activity (Masto et al., 2006). Only inorganic fertilizer either balanced or super optimal dose of NPK decreased dehydrogenase activity significantly compared to the combined application of inorganic chemical fertilizers and organic manures where a substantial mean increase (53.67 µg of TPF g^{1}) in dehydrogenase activity was recorded irrespective of growth stages of rice.

Effect of long term manuring on crop yield and harvest index (H. I.)

Perusal of results presented in Table 6 reveal that there was a significant variance with different treatments. However, the yield of rice and harvest index have been found to be increased due to different fertilization , being recorded highest yield of rice (51.57 q ha^{-1}) with harvest index (0.48) in the 100 % NPK + FYM treatment. In contrast application of balanced fertilization increase crop yield by directly supplying plant nutrients required for crop growth (Ren et al., 2014). The results of the present investigation also find support from the results of the long term experiments reported by Zhang et al. (2009). The higher or lower amounts of root exudates inputs into soil was associated with higher or lower amount of rice yield under different treatments (King et al., 2001). Among various treatments, the combined application of NPK+FYM and sole application of NPK produced more straw yields giving higher harvest index. Super optimal dose of NPK *i.e.*, 150 % produced higher yield than balanced fertilization *i.e.*, 100 % NPK (41.80 q ha^{-1}) but lower straw yield cause lower harvest index.

Table 6. Influence of organic amendments and inorganic fertilizers on yield and harvest index of rice under different fertilizer combination.

Treatments	Grain Yield(q/ha)	Harvest index
100 % NPK	41.80	0.47
150 % NPK	46.60	0.44
100 % NPK + FYM	51.57	0.47
100 % N	35.50	0.47
100 % NP	40.90	0.47
Control	21.95	0.44
LSD(P=0.05)	Grain yield = 4.83	Harvest index = 0.029

Table 7. Pearson's correlation coefficient (r) among different measured soil parameters.

	SOC	Av. N	MBC	MBN	DHA
SOC	1.00	0.84**	0.94**	0.89**	0.76*
Av. N	0.84**	1.00	0.80*	0.96**	0.71*
MBC	0.94**	0.80*	1.00	0.95**	0.75*
MBN	0.89**	0.96**	0.95**	1.00	0.67*
DHA	0.76*	0.71*	0.75*	0.67*	1.00

*, ** marked correlations are significant at p = 0.05 and 0.1 respectively.

Table 8. Relationship of different soil parameters with rice yield at different crop growth stages.

parameters	Maximum tillering stage		Panicle Initiation Stage		Maturity stage	
	Yield		Yield		Yield	
	Equation	R^2	Equation	R^2	Equation	R^2
SOC	Y = 2.14X + 19.85	0.71*	Y = 2.52X + 20.01	0.71*	Y = 11.64X + 20.01	0.79*
Av. N	Y = 0.26X - 18.96	0.84**	Y = 0.24X - 9.66	0.79*	Y = 0.31X - 20.14	0.91**
MBC	Y = 0.32X - 3.52	0.92**	Y = 0.29X + 8.22	0.92**	Y = 0.30X + 10.78	0.94**
MBN	Y = 0.29X + 17.16	0.89*	Y = -0.34 + 18.31X	0.88*	Y = 0.40X + 21.33	0.84**
DHA	Y = 0.44X + 28.82	0.74*	Y = 0.45 + 25.31	0.78*	Y = 0.54X + 28.32	O.76*

** and * next to R^2 values indicate significant a $p < 0.01$ and $p < 0.05$ respectively.

Unfertilized control plot showed significantly lowest yield (21.95 q ha^{-1}). Application of nitrogen alone @ 80 kg^{-1} ha increased yield by 61.73% over unfertilized control treatment. Application of phosphorus resulted in 15.21% of more yield over 100 % N treatment. Thus the treatments were in the order of 100% NPK+FYM > 150 % NPK > 100 % NPK > 100 % NP > 100 % N > control.

Relationship among different measured soil parameters and crop productivity

The coefficient of correlations amongst various parameters (Table 7) showed that all parameters were significantly correlated with each other. The microbial parameters namely MBC showed highest positive correlation with SOC content (r = 0.94**) and MBN content (r = 0.95**) which is in accord with Mandal et al. (2018). As regards to the change in MBN, it showed better correlation with Available N (r = 0.96**) and dehydrogenase activity showed highest correlation (r = 0.76*) with SOC. Such significant correlations among MBN, available N, SOC and dehydrogenase activity in the soil suggest the existence of a dynamic equilibrium among themselves. Significant relationships between rice yield and all soil parameters were observed (Table 8), the relationship being stronger particularly with MBC at maturity stage (R^2 = 0.94**) and panicle initiation stage (R^2 = 0.92**) and available nitrogen content at maturity stage (R^2 = 0.91**).

CONCLUSIONS

The experimental results clearly indicate that long term fertilization had greater impact on grain yield and soil fertility attributes under rice-rice rotation. Soil organic matter decomposition and nutrient availability can be enhanced by integration of balanced mineral fertilizer with organic amendments. Microbial biomass C, microbial biomass N, and dehydrogenase activity has a highly significant positive correlation with SOC and available N in soils. This demonstrates the importance of microbial parameters particularly for nutrient availability in soil and in general rice crop. Maximum tillering stage of rice growth played the most significant role to enhance nutrient availability. Regression results revealed that yield of rice was significantly correlated with MBC at all growth stages. So, mineral plus manure fertilizer in top dressing were recommended in wetland paddy soil. Long-term application of balanced and integrated use of fertilizers and organic manure is most desirable in order to improve nutrient availability in soil and crop yield.

ACKNOWLEDGEMENTS

Authors are grateful to AICRP on LTFE under ICAR for financial and technical support to conduct the experiment.

REFERENCES

Aulakh MS, Wassmann R, Bueno C, Kreuzwieser J and Rennenberg H(2001). Characterization of root exudates at different growth stages of ten rice (*Oryza sativa* L.) cultivars. Plant Biology 3: 139-148

Das SK and Varma A (2011). Role of enzymes in maintaining soil health. In: Shukla, G. & A. Varma (eds.) Soil Enzymology, Soil Biol Springer-Verlag Berlin Heidelberg pp. 25-42

Dhull SK, Goyal S, Kapoor KK and Mundra MC (2004). Microbial biomass carbon and microbial activities of soils receiving chemical fertilizers and organic amendments. Archives of Agronomy and Soil Science 50: 641-647

Dong W, Zhang XY, Dai X Q, Fu XL, Yang FT, Liu XY, Sun XM, Wen XF and Schaeffer S (2014). Changes in soil microbial community composition in response to fertilization of paddy soils in subtropical China. Applied Soil Ecology 84: 140-147

Ge GF, Li ZJ, Zhang J, Wang LG, Xu MG, Zhang JB, Wang JK, Xie XL and Liang YC (2009). Geographical and climatic differences in long-term effect of organic and inorganic amendments on soil enzymatic activities and respiration in field experimental stations of China. Ecological Complexity 6: 421-431

Ghosh P and Kashyap AK (2003). Effect of rice cultivars on rate of N-mineralization, nitrification and nitrifier population size in an irrigated rice ecosystem. Applied Soil Ecology 24: 27-41

Jackson ML(1973). Soil chemical analysis. - Prentic Hall of India Pvt. Ltd., New Delhi pp. 498

King JS, Kurt S, Pregitzer S, Zak DR, Kubisk ME, Ashby JA and Hoimes WE (2001). Chemistry and decomposition of litter from populous tremuloides Michauxgrown at elevated atmospheric CO and varying N availability. Global Change Biology 7: 65-74

Kumar PP, Thomas A, Pattanaik SSC, Kumar R, Kumar U and

Kumar A (2018). Effect of customised leaf colour chart (CLCC) based real time N management on agronomic attributes and protein content of rice (*Oryza sativa* L.). Oryza 55: 165-173

Luo P, Han X,WangY, Han M,Shi H, Liu N and Bai H (2015). Influence of long-term fertilization on soil microbial biomass, dehydrogenase activity, and bacterial and fungal community structure in a brown soil of northeast China. Annals of Microbiology 65: 533

Mandal A, Patra AK, Singh D, Swarup A and Masto RE (2007). Effect of long-term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. Bioresource Technology 98: 3585-3592

Mandal M, Rout KK, Purohit D, Majhi P and Singh M (2018). Evaluation of rice-rice system on grain yield, chemical, and biological properties of an acid *Inceptisol*. Journal of the Indian Society of Soil Science 66: 208-214

Masto RE, Chhonkar PK, Singh D and Patra AK (2006). Changes in soil biological and biochemical characteristics in a long-term field trial on a sub-tropical inceptisol. Soil Biology and Biohemistry 38: 1577-1582

Nayak AK, Gangwar B, Shukla AK, Mazumdar SP, Kumar A, Raja R, Kumar A, Kumar V, Rai PK and Udit Mohan (2012). Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice-wheat system in Indo Gangetic Plains of India. Field Crops Research 127: 129-139

Panda N, Raha P and Kumar A (2018). Microbial activity and plant nutrients transformation as influenced by herbicides application in soil. Oryza 55: 452-458

Purakayastha TJ, Huggins DR and Smith JL(2008). Carbon sequestration in native prairie, perennial grass, no-till, and cultivated palouse silt loam. Soil Science Society of American Journal 72: 534-540

Rees R and Castle K (2002). Nitrogen recovery in soils amended with organic manures combined with inorganic fertilizers. Agronomie 22: 739-746

Ren T, Wang J, Chen Q, Zhang F and Lu S (2014). The effects of manure and nitrogen fertiliser applications on soil organic carbon and nitrogen in a high input cropping system. PLoS ONE 9:e97732

Rice Almanac (2002). Third edition. Maclean, JL, Dawe DC, Hardey B and Hettel GP(eds). CABI Publishing

Shukla AK, Sharma SK, Tiwari R and Tiwari KN (2005). Nutrient depletion in the rice-wheat cropping system of the Indo-Gangetic plains. Better Crops 89: 28-31

Srinivasarao C, Kundu S, Grover M, Manjunath M, Sudhanshu SK, Patel JJ, Singh SR, Singh RP, Patel MM, Arunachalam A and Soam SK (2018). Effect of long term application of organic and inorganic fertilizers on soil microbial activities in semi-arid and sub-humid rainfed agricultural systems. Tropical Ecology 59: 99-108

Subbiah BV and Asija GL (1956). A rapid procedure for assessment of available nitrogen in soils. Currrent Science 31: 159- 160

Swaminathan MS (1993). Challenges and opportunities in rice research. - In: Proc. Int. Symp. New frontiers in Rice Research, November 15th-18th, Directorate of Rice Research, Hyderabad, India pp. 1-2

Tabatabai MA (1982). Soil Enzymes. In: Page AL, Miller RH, Keener DR(eds) Methods of soil analysis, vol 2: Chemical and microbiological properties.(Agronomy monograph no 9, 2nd edition) SA-SSSA, Madison, Wis. pp. 903-947

Vance ED, Brookes PC and Jenkinson DS (1987). An extraction method for measuring soil microbial carbon. Soil Biology Biochemistry 19: 703-707

Walkley AJ and Black JA(1934). Estimation of soil organic carbon by the chromic acidtitrationmethod. Soil Science 37: 29-38

Zhang WJ, Xu MG, Wang BR and Wang XJ (2009). Soil organic carbon, total nitrogen and grain yields under long term fertilisations in the upland red soils of Southern China. Nutrient Cycling and Agroecosystems 84: 59-69