Plant Archives Volume 20 No. 1, 2020 pp. 2629-2635 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

AVAILABILITY OF SOIL NITROGEN AND SOIL BIOLOGICAL ACTIVITY IN RICE-WHEAT CROPPING SYSTEM UNDER CONVENTIONAL AND CONSERVATION AGRICULTURAL PRACTICE

R. Mittal[1*], B. Chakrabarti[2], M. Rawat[1], R.S. Jatav[2] and R. Dhupper[1]

[1*]Amity Institute of Environmental Sciences, Amity University (Noida) India
[2]Centre for Environment Science and Climate Resilient Agriculture, ICAR- IARI, New Delhi.

Abstract

Conservation agricultural practices in rice-wheat cropping system could help in achieving food security and leading to a sustainable development. In the present study, field experiment was conducted for two consecutive years with rice and wheat crops to assess the effect of conservation agricultural practices on nitrogen availability and soil biological properties. Four different treatments were selected *i.e.* Transplanted rice + Conventionally tilled wheat (T_1), Direct seeded rice + Zero tilled wheat with residue retention (T_2), Transplanted rice + Zero tilled wheat (T_3), Transplanted rice + Zero tilled wheat with residue retention (T_4). Results showed that zero tillage along with residue retention in wheat increased microbial biomass as well as microbial activity in soil which increased availability of N to the crops. Multiple correlation analysis showed that soil available N was positively correlated with MBC (r = 0.83), MBN (r = 0.76) and dehydrogenase activity (r = 0.88) in soil. Treatments with residue retention had accumulation of more total organic carbon in soil. Higher soil carbon, more microbial activity and better nitrogen availability also increased yield of rice and wheat crops in zero tillage with residue applied treatment.

Key words : Conservation agriculture, Soil biological properties, Nitrogen availability, Grain and Straw yield.

Introduction

Rice-wheat cropping system covers an area of around 10.3Mha in India of which 85 percent falls in Indo Gangetic plains (IGP) (Ladha *et al.*, 2003; Timsina and Conor, 2001). Food security of the country is dependent on this production system feeding 40% of the country's population (Dhillon *et al.*, 2010; Panigrahy *et al.*, 2010). But in recent times the cropping system is showing lower marginal returns and there are reports of decline in physical and chemical properties of soil, nutrient mining as well as depletion of the groundwater table (Bhatt *et al.*, 2016 and Chauhan *et al.*, 2012). This intensively cultivated cropping system is also a source of greenhouse gas (GHG) emission from agriculture (Mittal *et al.*, 2018; Gupta *et al*, 2015). In order to overcome these challenges, conservation agricultural practices has emerged as a viable alternative for improving yield, increasing input use efficiencies along with reducing the harmful effect of agriculture on the environment. Conservation agriculture (CA) includes three main principles *i.e.* minimum soil disturbance, providing permanent soil cover and crop diversification (FAO, 2015). CA based management practices like zero tillage, zero tillage with residue incorporation, seeding in rice, crop diversification, laser levelling etc. are being adopted by farmers in the Indo Gangetic plains (IGP) (Pathak *et al.*, 2012). There are reports that conservation agricultural practices enhances yield, improves input use-efficiency, restores soil health, reduces cost of cultivation, and suppresses air and soil pollution (Chauhan *et al.*, 2002; Sapkota *et al.*, 2015 and Jat *et al.*, 2010). CA practices are also effective in enhancing soil carbon content (Bhattacharya *et al.*, 2012). In northwestern India certain CA practices like direct seeded rice is becoming popular to overcome the shortage of water and labour (Mahajan *et al.*, 2013). Besides this in rice-wheat cropping system, zero tillage and incorporation of rice residue in wheat field reduces the

***Author for correspondence :** E-mail: mittalrashmi6@gmail.com

weed growth and increases yield after 2 to 3 years of cultivation (Gathala *et al.*, 2011; Jat *et al.*, 2014 and Singh *et al*, 2005). Although work has been done on benefits of CA practices but the effect of these management practices on availability of nutrients and biological activity of soil is still limited. Keeping these in view, the present study was undertaken to assess the availability of nitrogen and biological activity of soil in rice-wheat cropping system under conventional and conservation agricultural practices.

Materials and Methods

Details of study site

Farmer's field with rice-wheat cropping system was selected in Taraori village in Karnal district, Haryana. The site is located at 29.7ºN and 76.9ºE with sub-tropical monsoon climate. The average annual rainfall of the region was 700 mm and the mean annual maximum and minimum temperatures were 35°C and 18°C respectively. The soil of the experimental field was sandy clay loam in texture with pH 8.1 and soil organic carbon 0.46 %. The experimental field was under continuous rice-wheat cropping system for more than 10 years. Pusa1121 variety of rice and HD2967 variety of wheat were grown in the fields.

Experimental Design and Treatments

In the current study the field experiment was conducted for two consecutive crop years for rice and wheat in 2015–2016 and 2016–2017. There were four treatments *viz*; 1. Transplanted rice + conventionally tilled wheat (T_1) 2.Direct seeded rice + Zero tilled wheat with residue retention (T_2), 3.Transplanted rice + Zero tilled wheat (T_3), 4.Transplanted rice + Zero tilled wheat with residue retention (T_4). The design of the experiment was randomized block design (RBD) with plot size of 7.5m × 6m. Plots with the four treatments were randomized with five replicates each. N, P and K were applied at recommended doses of 120 kg N, 60 kg P_2O_5 and 60 Kg K_2O respectively in both the crops. Nitrogen fertilizer was applied in three equal splits *i.e.* at sowing, tillering and panicle initiation stages in rice. Similarly in wheat, nitrogen was applied in three equal splits at sowing, crown root initiation (CRI) and remaining one at booting stage. Crop protection measures like herbicide and weedicides spray were carried out as and when required. Need based weeding was done in both the crops. In transplanted rice irrigation was applied every alternate day to maintain 6 cm water depth in the field, whereas in direct seeded rice (DSR), irrigation was applied every 4 to 5 days to maintain soil water content at field capacity. In wheat, 5 irrigations were applied at sowing, CRI, tillering, booting and flowering stages. In the next year of experiment, both rice and wheat crop treatments were grown in the same plot area as that of previous year.

Collection and analysis of soil samples

Initial soil samples were collected and then samples were collected at flowering stage and after harvesting of each crop. Soil samples were collected from 0 to 15 cm depth from all four treatments. Each sample was divided into 2 parts, one being stored at 4°C in refrigerator and the other kept in shade for air drying. The air dried samples were processed and sieved using 0.5 mm screen and stored in plastic jars for further analysis. The refrigerated samples were used for analysis of soil biological properties and enzymatic activities.

Analysis of different soil parameters

Available nitrogen

Available nitrogen in soil was estimated from fresh soil samples collected at flowering stage of the crops. Soil available N was analysed using Subbiah and Asija (1956) method.

Total organic carbon in soil

Total carbon content (TOC) in soil was analysed by the dry combustion method (950°C) (Nelson and Sommers 1982). Vario TOC select elementar analyzer (Serial no.-39112009) Inc. Hanau, Germany was used for the analysis. Representative subsamples of soil were taken and weighed on a tin foil. Soil samples along with tin foils were injected into the combustion reactor at a temperature 950°C in an air carrier gas stream. Evolved CO_2 was dried and measured by non-dispersive infrared detector (NDIR) which absorbs infrared energy by CO_2 at a wavelength (2.6µ and 4µ), LECO; 1996. The decrease in the measured energy is directly proportional to the CO_2 concentration in terms of percent carbon in soil.

Microbial biomass carbon and microbial biomass nitrogen

Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) in soil were estimated from fresh samples collected at flowering stage using fumigation extraction method as given by Jenkinson and Powlson (1976).

Dehydrogenase activity

Dehydrogenase activity in fresh soil samples collected at flowering stage was determined using the method given by Klein *et al.*, (1971).

Yield attributes

Rice and wheat crops were harvested and threshed manually from $1m^2$ area from each plot for every treatment. Weight of dried straw and grain biomass were recorded and reported in units of Mg ha^{-1}.

Statistical analysis

Statistical analysis of the experimental data was done by using ANOVA (analysis of variance) technique recommended for the design to check whether the differences bsetween means were statistically significant or not (Gomez and Gomez, 1984). Unless indicated otherwise, differences were considered significant at $P<0.05$.

Results and Discussion

Grain and straw yield

Grain yield of both rice and wheat crop was affected by different crop management practices. Rice yield was maximum (4.16 Mg ha^{-1} in first year and 4.36 Mg ha^{-1} in second year) in T_4 treatment in both the years (Table 1). On the other hand T_2 treatment with direct seeded rice recorded 3.51 and 3.73 Mg ha^{-1} grain yield in first and second year respectively which was significantly lower than T_1 treatment (transplanted rice). Similarly straw yield was also lowest in direct seeded rice in both the years (Table 2). Zero tilled wheat with residue retention (T_4 treatment) recorded highest grain yield of 4.89 and 5.27 Mg ha^{-1} in first and second year respectively (Table 1). Straw yield of wheat was also maximum in T_4 treatment with 6.63 Mg ha^{-1} and 7.21 Mg ha^{-1} in first and second year respectively (Table 2). Ram *et al*., (2013) reported that rice residue incorporation enhanced grain yield and water use efficiency in wheat crop. Sarwar *et al.*, (2008) reported that crop residue in combination with chemical fertilizer significantly enhanced the biological yield of rice. There are reports that adequate crop rotation, continuous zero tillage practices with crop residue retention results in higher crop yield under both favorable or adverse climatic conditions (Congreves *et al.*, 2015, Kassam *et al.*, 2014).

Soil biological properties

Soil microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were higher in T_2, T_3 and T_4 treatments as compared to T_1 (Fig. 1 and 2). Maximum value of MBC was observed in T2 treatment (555.6 mg kg^{-1}) followed by T_4 treatment (548.2 mg kg^{-1}) in second wheat crop. Similar trend was observed in the first wheat crop where MBC was maximum in T_4 (538 mg kg^{-1}) followed by T_2 (507.9 mg kg^{-1}). MBN of soil was also higher in T_2 and T_4 treatment under wheat crop. MBN values ranged from 41.9 to 56.9 mg kg^{-1} in rice and 53.4 to 73.5 mg kg^{-1} in wheat crop. In T4 treatment, soil MBN was 56.9 mg kg^{-1} followed by T_2 (54 mg kg^{-1}) during second year under rice crop. Retention of rice residue in both these treatments led to the increased microbial activity thereby increasing MBC and MBN of soil. Choudhary *et al.*, (2018) also reported that zero tillage maize-wheat-mungbean rotation recorded 56% increase in microbial biomass carbon and 70% increase in microbial biomass nitrogen than conventional tillage rice-wheat system, This might be attributed to the reduced tillage along with increased carbon inputs added to soil through residue application (Wang *et al.*, 2012). Increased microbial biomass also enhanced the microbial activity which was evident from the higher dehydrogenase activity of soil in T_2, T_3 and T_4 treatment. Dehydrogenase activity of soil ranged from 1.06 to 1.27 mg TPF g^{-1} h^{-1} during the 2 years of rice-wheat cultivation (Fig. 3). T4 treatment recorded maximum values of dehydrogenase activity (1.57 mg TPF g^{-1} h^{-1}) in second wheat crop. The

Table 1: Grain yield (Mg ha^{-1}) of rice and wheat crop under different management practices during 2015-2017

Treatments	2015-16		2016-17	
	Rice	Wheat	Rice	Wheat
T_1	4.01	4.39	4.10	4.98
T_2	3.51	4.42	3.73	5.03
T_3	4.09	4.40	4.20	5.08
T_4	4.16	4.89	4.36	5.27
LSP ($P \leq 0.05$)	0.25	0.20	0.20	0.29

Table 2: Straw yield (Mg ha^{-1}) of rice and wheat crop under different management practices during 2015-2017

Treatments	2015-16		2016-17	
	Rice	Wheat	Rice	Wheat
T_1	6.26	6.23	6.87	6.74
T_2	6.34	6.51	6.36	6.81
T_3	6.11	6.23	6.53	6.74
T_4	6.38	6.63	6.81	7.21
LSP($P \leq 0.05$)	0.20	0.22	0.23	0.32

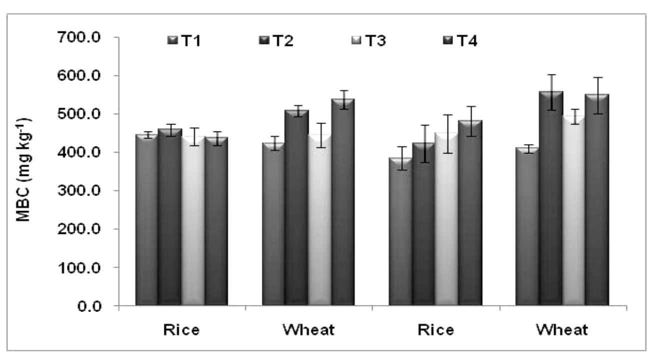

Fig. 1: Microbial biomass carbon (Mg kg^{-1}) in soil under different management practices during 2015-2017

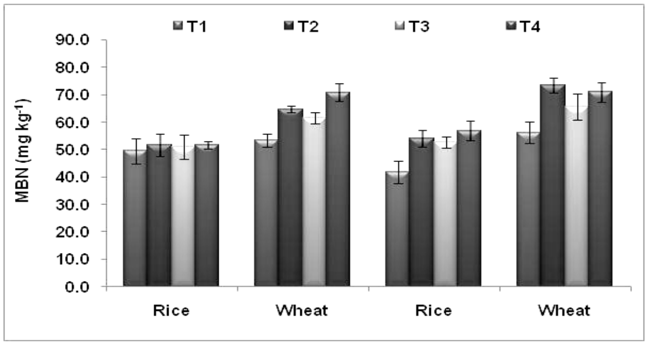

Fig. 2: Microbial biomass nitrogen (Mg kg^{-1}) in soil under different management practices during 2015-2017

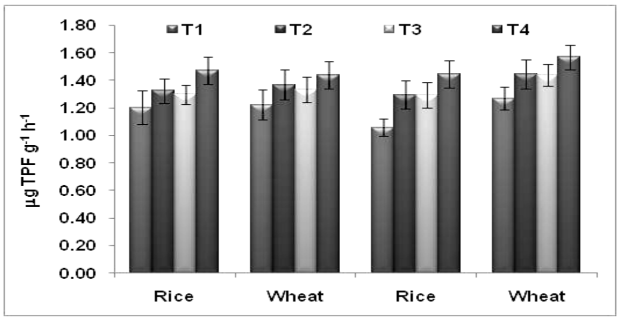

Fig. 3: Dehydrogenase activity (mg TPF g^{-1}h^{-1}) in soil under different management practices during 2015-2017

soil under zero tillage and zero tillage along with residue retention retains higher soil moisture than conventional tillage systems (Pathak *et al*., 2017). This in turn influences the moisture availability which finally affects the enzymatic activities in soil (Jin *et al.,* 2009).

Total nitrogen and available nitrogen in soil

Total N in soil ranged from 0.11 to 0.16%. After 2 years of cultivation total N in soil slightly increased in different treatments (Fig. 4). A significant variation in soil available nitrogen was observed during the two years of rice wheat cropping system. In rice crop available N ranged from 378 to 491.5 kg ha^{-1} whereas in wheat crop it ranged from 390 to 531.9 kg ha^{-1} (Table 3). Maximum available N in soil (531.9 kg ha^{-1}) was recorded in T4 treatment in first wheat crop. Rahman *et al*., (2005) reported that higher nitrogen fertilizer recovery could be achieved possibly by crop residue incorporation. Earlier workers also reported that retention of nutrient rice crop residue along with minimum soil disturbance resulted in increased availability of nitrogen in soil surface under CA management practices (Jat *et al.,* 2018; Chakrabarti *et al*., 2014).

Table 3: Soil available nitrogen (kg ha^{-1}) under different management practices in rice-wheat cropping system during 2015-2017

Treatments	2015-16		2016-17	
	Rice	Wheat	Rice	Wheat
T_1	378.0	409.4	354.8	390.0
T_2	397.5	462.7	374.6	480.7
T_3	400.6	420.5	448.7	457.1
T_4	485.9	531.9	491.5	525.5
LSP ($P \leq 0.05$)	31.1	19.6	22.8	26.6

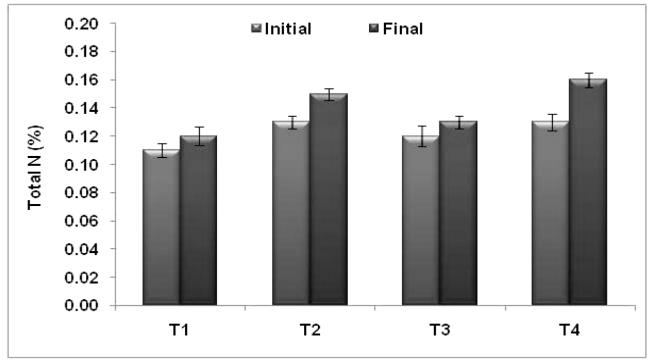

Fig. 4: Total nitrogen (%) in soil under different management practice

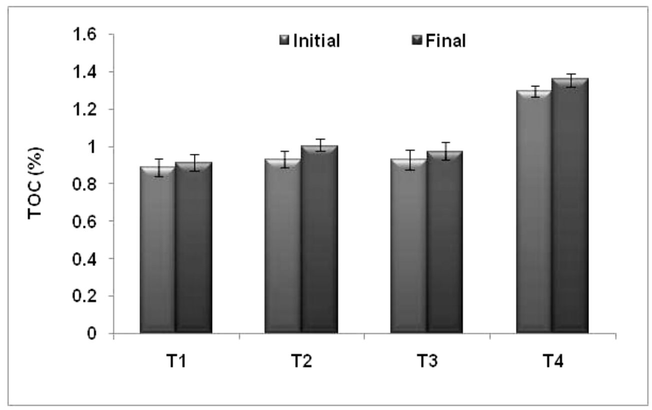

Fig. 5: Total organic carbon (%) in soil under different management practices

Organic carbon in soil

Total organic carbon in soil increased significantly after 2 years of cropping sequence in T_2 and T_4 treatment. Maximum value of soil organic carbon (1.36%) was found in T_4 treatment (Fig. 5). Rice residues applied to soil in T_2 and T_4 treatments were a source of organic matter which after microbial degradation enriched the carbon status (Chakrabarti *et al.,* 2014). T_3 treatment with direct seeded rice and zero tilled wheat also recorded higher values of soil carbon (0.97%) as compared to T_1 treatment (0.91%). Conventional tillage in T_1 treatment broke the soil aggregates thereby exposing the soil for rapid organic matter decomposition. Chauhan *et al.*, (2002) stated the importance of zero tillage for enhancing organic matter content in surface soil. There are reports that conservation tillage leads to soil carbon sequestration in long-term experiments (Rudrappa *et al.,* 2006; Singh *et. al*, 2004).

Table 4: Correlation matrix of yield and soil parameters in rice-wheat cropping system

	Available N	Total N (%)	TOC (%)	MBC	MBN	Dehydrogenase	Grain Yield	Straw Yield
Available N	1							
Total N (%)	0.72*	1.00						
TOC (%)	0.83*	0.76*	1.00					
MBC	0.83*	0.73*	0.54*	1.00				
MBN	0.76*	0.65*	0.43	0.90*	1.00			
Dehydrogenase	0.88*	0.77*	0.76*	0.79*	0.77*	1.00		
Grain Yield	0.61*	0.40	0.36	0.61*	0.77*	0.53*	1.00	
Straw Yield	0.39	0.55*	0.42	0.45	0.38	0.29	0.62*	1

* Significant at $p \leq 0.05$ level.

Correlation and regression analysis

Multiple correlation analysis showed that soil available N was positively correlated with MBC (r = 0.83), MBN (r = 0.76) and dehydrogenase activity (r = 0.88) in soil (Table 4). This proves that increased microbial biomass as well as microbial activity in soil under conservation agricultural practices led to increased availability on N to the crops. This enhanced N availability also increased the grain yield which is evident from the significant positive correlation between soil available N (r = 0.61) in the study. Total organic carbon soil was also found to be positively correlated with MBC (r = 0.54) and dehydrogenase activity (r = 0.76). Treatments with residue application have led to more accumulation of microbial biomass and enhanced microbial activity which led to the accumulation of more organic carbon in soil in residue applied treatments.

Conclusion

Changes in soil available nitrogen (0-15 cm depth) due to implementation of treatments for two consecutive years revealed that zero tillage in wheat with residue retention performed better in terms of soil enzymatic and microbial biomass as compared to conventional wheat. Increased microbial activity in turn increased availability of N in soil. Treatments with residue retention had accumulation of more organic carbon in soil. Grain yield was also high in zero tillage with residue retention treatment. From the present study it can be concluded that zero tillage with residue retention in wheat along with transplanted rice could enhance nitrogen availability and hence increase crop productivity.

Acknowledgements

This research was financially supported by National Innovations in Climate Resilient Agriculture, Indian Council of Agricultural Research. The authors acknowledge the farmers of Taraori village at Karnal district of Haryana for providing experimental field and other key inputs for ease of conducting research. The authors are thankful to ICAR-Indian Agricultural Research Institute, New Delhi, for providing the facilities for the research. Authors are also thankful to Division of Agricultural Physics, ICAR-IARI, New Delhi for providing the TOC analyzer for sample analysis. Thanks to the collaboration and support of AMITY University, Noida.

References

Bhatt, R., S.S. Kukal, M.A. Busari, S. Arora and M. Yadav (2016). Sustainability issues on rice–wheat cropping system. *International Soil and Water Conservation Research*, **4(1):** 64-74.

Bhattacharyya, R., M.D. Tuti, S. Kundu, J.K. Bisht, Gupta and J.C. Bhatt (2012). Conservation Tillage Impacts on Soil Aggregation and Carbon Pools in a Sandy Clay Loam Soil of the Indian Himalayas. *Soil Sci. Soc. Am. J.,* **76(2):** 617-627.

Chakrabarti, B., P. Pramanik, U. Mina, D.K. Sharma and R. Mittal (2014). Impact of conservation agricultural practices on soil physic-chemical properties. *International Journal on Agricultural Sciences*, **5(1):** 55-59.

Chauhan, B.S., G. Mahajan, V. Sardana, J. Timsina and M.L. Jat (2012). Productivity and sustainability of the rice–wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: problems, opportunities, and strategies. In *Advances in Agronomy,* **117:** 315-369. Academic Press.

Chauhan, B.S., A. Yadav and R.K. Malik (2002). Zero tillage and its impact on soil properties: A brief review. *Herbicide Resistance Management and Zero Tillage in Rice–Wheat System*, 109-114.

Choudhary, M., P.C. Sharma, H.S. Jat, A. McDonald, M.L. Jat, S. Choudhary and N. Garg (2018). Soil biological properties and fungal diversity under conservation agriculture in Indo-Gangetic Plains of India. *Journal of soil science and plant nutrition*, **18(4):** 1142-1156.

Congreves, K.A., A. Hayes, E.A. Verhallen and L.L.Van Eerd (2015). Long-term impact of tillage and crop rotation on soil health at four temperate agroecosystems. *Soil and*

Tillage Research, **152:** 17-28.

Dhillon, B.S., P. Kataria and P.K. Dhillon (2010). National food security vis-à-vis sustainability of agriculture in high crop productivity regions. *Current Science*, 33-36.

FAO. (2015). Conservation Agriculture. Available online at: http://www.fao.org/ag/ca/index.html (Accessed January 4, 2015).

Gathala, M.K., J.K. Ladha, V. Kumar, Y.S. Saharawat, V. Kumar, P.K. Sharma and H. Pathak (2011). Tillage and crop establishment affects sustainability of South Asian rice–wheat system. *Agronomy Journal*, **103(4):** 961-971.

Gomez, K.A. and A.A. Gomez (1984). Statistical procedures for Agricultural Research. John Wiley and Sons, New York.

Gupta, D.K., A. Bhatia, A. Kumar, B. Chakrabarti, N. Jain and H. Pathak (2015). Global warming potential of rice (Oryza sativa)-wheat (*Triticum aestivum*) cropping system of the Indo-Gangetic Plains. *Indian J. Agric. Sci*., **85(6):** 807-816.

Jat, H.S., A. Datta, P.C. Sharma, V. Kumar, A.K. Yadav, M. Choudhary and N.P.S. Yaduvanshi (2018). Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. *Archives of Agronomy and Soil Science*, **64(4):** 531-545.

Jat, R.K., T.B. Sapkota, R.G. Singh, M.L. Jat, M. Kumar and R.K. Gupta (2014). Seven years of conservation agriculture in a rice–wheat rotation of Eastern Gangetic Plains of South Asia: Yield trends and economic profitability. *Field Crops Research*, **164:** 199–210.

Jat, M.L., Y.S. Saharawat and R. Gupta (2010). Conservation agriculture: improving resource productivity in cereal systems of South Asia. National Symposium on Resource Management Approached Towards Livelihood Security, XIX; Bengaluru, Karnataka,(India); 2-4 Dec 2010.

Jenkinson, D.S. and D.S. Powlson (1976). The effects of biocidal treatments on metabolism in soil-V: A method for measuring soil biomass. *Soil biology and Biochemistry*, **8(3):** 209-213.

Jin, K., S. Sleutel, D. Buchan, S. De Neve, D.X. Cai, D. Gabriels and J.Y. Jin (2009). Changes of soil enzyme activities under different tillage practices in the Chinese Loess Plateau. *Soil Till. Res*., **104:** 115-120.

Kassam, A., R. Derpsch and T. Friedrich (2014). Global achievements in soil and water conservation: The case of Conservation Agriculture. *International Soil and Water Conservation Research*, **2(1):** 5-13.

Klein, D.A., T.C. Loh and R.L. Goulding (1971). A rapid procedure to evaluate the dehydrogenase activity of soils low in organic matter. *Soil Biology and Biochemistry*, **3(4):** 385-387.

Ladha, J.K., C.S. Khind, R.K. Gupta, O.P. Meelu and E. Pasuquin (2004). Long-term effects of organic inputs on yield and soil fertility in the rice–wheat rotation. *Soil Science Society of America Journal*, **68(3):** 845-853.

Ladha, J.K., H. Pathak, A. Tirol-Padre, D. Dawe and R.K. Gupta (2003). Productivity trends in intensive rice–wheat cropping systems in Asia. *Improving the Productivity and Sustainability of Rice–Wheat systems: Issues and Impacts*, (improving the pro), 45-76.

LECO. (1996). CNS-2000 Elemental Analyzer - Instruction Manual. LECO Corp., St. Joseph, MI.

Mahajan, G., B.S. Chauhan and M.S. Gill (2013). Dry-seeded rice culture in Punjab State of India: lessons learned from farmers. *Field Crops Research*, **144:** 89-99.

Mittal, R., B. Chakrabarti, T. Jindal, A. Tripathi, U. Mina, R. Dhupper, D. Chakraborty, R.S. Jatav and R.C. Harit (2018). Carbon footprint is an indicator of sustainability in Rice-Wheat cropping system: A Review. *Chemical Science Review and Letters*, **7(27):** 774-784.

Nelson, D.W. and L. Sommers (1982). Total carbon, organic carbon, and organic matter 1. *Methods of soil analysis. Part 2. Chemical and microbiological properties*, (methodsofsoilan2), 539-579.

Panigrahy, S., G. Upadhyay, S.S. Ray and J.S. Parihar (2010). Mapping of cropping system for the Indo-Gangetic plain using multi-date SPOT NDVI-VGT data. *Journal of the Indian Society of Remote Sensing*, **38(4):** 627-632.

Pathak, H., B. Chakrabarti, U. Mina, P. Pramanik and D.K. Sharma (2017). Ecosystem services of wheat (*Triticum aestivum*) production with conventional and conservation agricultural practices in the Indo-Gangetic Plains. *Indian Journal of Agricultural Sciences*, **87(8):** 987-91.

Pathak, H., A.R. Sharma, T.K. Das and M.L. Jat (2012). Adaptation and mitigation of climate change with conservation agriculture. *Climate Change Impact, Adaptation and Mitigation in Agriculture: Methodology for Assessment and Application*, 223-241.

Rahman, M.A., J. Chikushi, M. Saifizzaman and J.G. Lauren (2005). Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. *Field Crops Research*, **91(1):** 71-81.

Ram, H., V. Dadhwal, K.K. Vashist and H. Kaur (2013). Grain yield and water use efficiency of wheat (*Triticum aestivum* L.) in relation to irrigation levels and rice straw mulching in North West India. *Agricultural Water Management*, **128:** 92-101.

Rudrappa, L., T.J. Purakayastha, D. Singh and S. Bhadraray (2006). Long-term manuring and fertilization effects on soil organic carbon pools in a Typic Haplustept of semi-arid sub-tropical India. *Soil and Tillage Research*, **88(1-2):** 180-192.

Sapkota, T.B., M.L. Jat, J.P. Aryal, R.K. Jat and A. Khatri-Chhetri (2015). Climate change adaptation, greenhouse gas mitigation and economic profitability of conservation agriculture: Some examples from cereal systems of Indo-Gangetic Plains. *Journal of Integrative Agriculture*, **14(8):** 1524-1533.

Sarwar, G., H. Schmeisky, N. Hussain, S. Muhammad, M. Ibrahim and E. Safdar (2008). Improvement of soil physical and chemical properties with compost application in rice-wheat cropping system. *Pakistan Journal of Botany*, **40(1):** 275-282.

Singh, Y. and H.S. Sidhu (2014, March). Management of cereal crop residues for sustainable rice-wheat production system in the Indo-Gangetic plains of India. In *Proc. Indian Natl. Sci. Acad.*, **80(1):** 95-114.

Subbaiah, B.V. (1956). A rapid procedure for estimation of available nitrogen in soil. *Curr. Sci.*, **25:** 259-260.

Timsina, J. and D.J. Connor (2001). Productivity and management of rice–wheat cropping systems: issues and challenges. *Field crops research*, **69(2):** 93-132.

Wang, J.J., X.Y. Li, A.N. Zhu, X.K. Zhang, H.W. Zhang and W.J. Liang (2012). Effects of tillage and residue management on soil microbial communities in North China. *Plant, Soil and Environment*, **58(1):** 28-33.