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CONSERVATION TILLAGE, OPTIMAL WATER AND ORGANIC NUTRIENT SUPPLY ENHANCE SOIL MICROBIAL ACTIVITIES DURING WHEAT (*TRITICUM AESTIVUM L.*) CULTIVATION

Pankaj Sharma[1, 2], Geeta Singh[2], Rana P.Singh*[1]

[1]Department of Environmental Science, Babasaheb Bhimrao Ambedkar University, Rae Bareily Road, Lucknow-226025, India;
[2]Division of Microbiology, Indian Agricultural Research Institute, Pusa Road, New Delhi-110012, India.

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ABSTRACT

The field experiments were conducted on sandy loam soil at New Delhi, during 2007 and 2008 to investigate the effect of conservation tillage, irrigation regimes (sub-optimal, optimal and supra-optimal water regimes), and integrated nutrient management (INM) practices on soil biological parameters in wheat cultivation. The conservation tillage soils has shown significant ($p<0.05$) increase in soil respiration (81.1%), soil microbial biomass carbon (SMBC) (104%) and soil dehydrogenase (DH) (59.2%) compared to the conventional tillage soil. Optimum water supply (3-irrigations) enhanced soil respiration over sub-optimum and supra-optimum irrigations by 13.32% and 79% respectively. Soil dehydrogenase (DH) activity in optimum water regime has also increased by 23.33% and 8.18% respectively over the other two irrigation regimes. Similarly, SMBC has also increased by 12.14% and 27.17% respectively in soil with optimum water supply compared to that of sub-optimum and supra-optimum water regime fields. The maximum increase in soil microbial activities is found when sole organic source (50% Farm Yard Manure+25% biofertilizer+25% Green Manure) has been used in combination with the conservation tillage and the optimum water supply. Study demonstrated that microbial activity could be regulated by tillage, water and nitrogen management in the soil in a sustainable manner.

Key words: Conservation Tillage, Integrated Nutrient Management (INM), Soil Respiration, Soil Microbial Biomass Carbon (SMBC), Dehydrogenase Activity (DH).

INTRODUCTION

India contributes approximately 12% (77.63 mt) of the global wheat (*Triticum aestivum L.*) production (12). It is an input intensive crop, grown on 13% of the cropped area in the Indo-Gangetic plains (IGP). Wheat is cultivated as a component of rice-wheat cropping system (RWCS) in IGP. The majority of Indian soils are low in N and therefore loading of urea (46% N) is practiced. Integrated nutrient management practices and resource conservation technologies are used to enhance crop productivity in sustainable agriculture (19). This has become more important in the wake of global climate

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***Corresponding Author. Mailing address:** School for Environmental Sciences, Babasaheb Bhimrao Ambedker University, Rae Bareily Road, Lucknow-226025, India.; Fax no: +91522441888, Mobile: +919889121823.; E-mail: ranapsingh1@hotmail.com

change which demands more judicious use of available resources. Thus, the major target in the regime of global climate change is water and energy conservation (26).

Tillage affects the physical, chemical, and biological properties of the soil (34). A proper tillage can alleviate soil-related constraints whereas an improper tillage leads to a deterioration in soil structure. The latter further accelerated erosion, depletion of soil organic matter (SOM) and soil fertility as well as the disruption of the nutrient cycle (15, 25). The conservation and addition of SOM are crucial for biological, chemical and physical soil functionality and nutrient cycling particularly of N. The N-cycling largely depends on the microbial activities in the soil (9). The conservation tillage improves soil organic carbon (SOC) concentration, water storage and reduces soil erosion, and subsequently enhances soil quality and resilience (21). It also increases SMBC (18), activities of several soil enzymes (20, 23) as well as the soil respiration (40).

Microbial activities affect nutrient cycling and the availability of inorganic nutrients. The improved nutrient cycling leads to soil fertility and subsequently enhance plant growth and the crop yield (4). Soil enzymes and microbial biomass have been considered as the major indicators of soil quality due to their relationship to soil fertility, ease of measurement, and high sensitivity to changes originated by the management and environmental factors (7). Experiments have revealed a positive correlation between soil management systems and agriculturally beneficial microorganisms (17).

Many factors affect the sustainability of wheat production under the RWCS. Some important factors are SOM content, indigenous nutrient supply (14), the micronutrient, ground water, percolation (1) etc. In order to overcome these limitations and to sustain crop productivity and soil fertility, a system (multicomponent) approach involving INM practices, i.e. water conservation strategies, conservation tillage and application of organic nutrients may yield good substitute of conventional green revolution practices for wheat cropping. Erenstein et al. (8), and Sahrawat et al. (31), have reported higher or almost equal yield for rice-wheat cropping system under conservation tillage as compared to conventional tillage. Though, an integrated approach for tillage, water and nutrient management for wheat crop has not been reported.

Therefore, experiments were undertaken to study the combined effect of integrated nitrogen application, water regimes, and tillage practices on soil (micro) biological indices during wheat cultivation.

MATERIALS AND METHODS

Experimental Location: The field experiments were conducted at the research farm of Indian Agriculture Research Institute, New Delhi, during the winter (Rabi) season of 2007 and 2008. The latitude of New Delhi is 28°38 N and longitude is 77°12 E and its height above mean sea level is 216 m.

Physical and Chemical Analysis of Soil: The top soil (0-15 cm) was sandy clay-loam which was followed by a loamy lower layer (15-90 cm) with field capacity 19-20% (w w^{-1}) and permanent wilting point 7-11% (w w^{-1}). It had pH 7.7, organic C (0.68) (16), 159-163 kg ha^{-1} alkaline permanganate hydrolysable N (37), 14 kg ha^{-1} 0.5 m $NaHCO_3$ extractable P (27) and 296 kg ha^{-1} 1N NH_4OAc exchangeable K (16) determined by the procedures described by Prasad et al. (29).

Experimental Design: The experiments were laid out in split-plot design. Two main plots were divided for two tillage treatments (i.e. conservation and conventional), which were further divided in sub-plots for three different irrigation treatments (i.e. sub-optimum, optimum and supra-optimum). The sub-plots were further divided in sub-sub plots for different nutrient treatments as mentioned in Table 1. The treatments comprised of two tillage (i.e. Zero/conservation tillage and conventional tillage) were maintained in all the plots. Water management consisting of three water regimes; 2-irrigations (sub-optimal), 3- irrigation (optimal) and 5-irrigations (supra-optimal) were allocated in the sub-plots (each at a gap of 20 days). The eight nitrogen sources applied to the wheat plots are as in Table 1.

The three replicates (i.e. n=3) were maintained for each nutrient treatment. The recommended dose of N in this region for wheat is 120 kg ha^{-1} (34). The wheat cultivar (cv.) 'HD 2876' seeds were sown during the last week of October 2007 and 2008 at the 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 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 remaining two doses in two equal parts as top dressing at tillering and panicle initiation stages of wheat in the amount mentioned in Table 1. The quantity of well decomposed FYM containing 0.5 percent N (i.e. 0.05 Kg N Kg^{-1} of FYM) on dry-weight basis was calculated by Kjeldahl's method and incorporated in the soil as a green manure (GM) before sowing. Similarly, *Sesbania aculeate* was applied at 10.5 t ha^{-1} before seeding of wheat. The 25% of urea as biofertilizer (*Azospirillium brasilense*) CDJA; received from Dr. J. Dobereiner, Brazil). The *Azospirillium brasilense* strain fixes 25-30% (of RDN) N ha^{-1}. The coating of seeds with biofertilizer has been achieved by dipping the seeds in aqueous suspension culture of the biofertilizer. The inoculums density was 10^{8} cells ml^{-1} (41). A measured quantity of water through a 7.62 cm Parshall Flume was applied at the rate of 40 mm in each irrigation, as per treatment. During the crop period, a total rainfall of 112.0 and 111.8 mm were received during the 2007 and 2008, respectively. While relative humidity was 71 and 68.2 respectively and mean temperature was 18.24°C and 18.46°C.

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

Treatments / N-Source	Composition
T_0	Control
T_1	RDN through urea + 33 kg ha^{-1} P added as rock phosphate, No 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

*Here T represents and respective numerals i.e. 1, 2 ….7 represents respective no. of treatments; N, represents Nitrogen, P, Phosphorus and K, Potassium

Estimation of Soil Respiration, Dehydrogenase and Soil Microbial Biomass Carbon (SMBC): Soil samples were collected from a depth of 0-15 cm immediately after the harvest of wheat crop. Six sub-samples per treatment were composited. The field moist samples were sieved to 2 mm and analyzed for: respiration, dehydrogenase activity and microbial biomass carbon content in the soil. The microbial biomass carbon was estimated following chloroform fumigation extraction method (39). The soil respiration was measured by the method prescribed by Stotzky (36). The soil dehydrogenase enzyme (DH) activity was estimated by the method given by using Casida et al. (3).

Chemicals and Equipments used: All chemicals used were Sigma Chemicals, India situated in Badlapur district of Thane, Mumbai. All equipments used were of Borosil Company. Borosil is certified by ISO 9001. Manufacturing unit of Borosil is situated in Worli, Mumbai – India.

Statistical Analysis: All the data recorded were analysed by using the standard procedure of statistical analysis for split-plot design (11). Analysis of variance (ANOVA) was used to determine the effect of each treatment, when the F-ratio was significant; a multiple mean comparison was performed using C.D. (Critical Difference) (0.05 probability level) values. The data has been analysed by statistical package MSTAT.

RESULTS

Soil Respiration

The data presented in Table 2 indicate that a significant soil respiration (81.1%) is determined in zero-tillage plots, over the conventional tillage plots. Zero tillage condition has brought about significant soil respiration compared to conventional tillage. Among the integrated nitrogen management treatments, the highest rate of soil respiration was recorded in treatments where the N requirement has been made available through a sole organic source (of N) (i.e. T_6) (i.e. 32.72 mg CO_2 (100 g)$^{-1}$ soil) followed by the treatment T_5 (i.e. 32.22 mg CO_2 (100 g)$^{-1}$ soil. These values showed significant ($p<0.05$) soil respiration as compared to the control plots. For a given nutrient management practice, the three different water regimes significantly affected the soil respiration activity. Soil receiving sole organic source during 3-irrigation recorded 10.3% and 23.7% higher soil respiration compared to 2-irrigation and 5- irrigation respectively (Table 3). The use of urea as a sole N-source brought about a decrease of 38.87% and 32.28% in soil respiration under 2- irrigation and 5-irrigation respectively, compared to 3- irrigation. The substitution of sewage sludge for 25% RDN showed statistically identical value of soil respiration under 2-irrigation and the 5- irrigation but significantly higher soil respiration in plots with 3- irrigation.

The most important parameter influencing the soil respiration has been tillage regime, however, the treatment where the sole organic source has been used as N-source along with optimum irrigation provide better results as compared to other nutrient treatments and irrigation regimes respectively.

Soil Dehydrogenase Activity (DH)

The zero tillage (conservation tillage) soil has brought about significant soil dehydrogenase activity i.e.59.2% compared to the conventional tillage soil in the wheat fields of IGP (Table 2). The frequency of irrigation has also affected soil dehydrogenase activity. The maximum soil dehydrogenase activity (1.85 µg TPF g^{-1} soil h^{-1}) has been observed in 3-irrigation plots, followed by 5- irrigation (1.71 µg TPF g^{-1} soil h^{-1}) and 2- irrigation (1.50 µg TPF g^{-1} soil h^{-1}) plots (Table 4). Among the nutrient treatment sole organic source is found to be most effective. It brought about 12.5% increases in dehydrogenase activity compared to control. The next higher value has been observed with T_5 treatment (Table 2). Other plots having RDN in various forms also had higher soil dehydrogenase activity compared to control plots. The conservation tillage plots with 3-irrigations have brought about significantly higher soil dehydrogenase activity over the conventional tillage plots in all the studies (Table 4). The maximum soil DH has been, however, observed in the plots applied with conservation tillage, 3- irrigation and sole N supply through the organic sources i.e. FYM + biofertilizer + GM which were closely followed when 75% N was urea and 25% as biofertilizer.

Integrated nutrient treatments, where the RDN has been substituted with sole organic source under zero tillage registered 74.9% increase in DH activity compared to conventional tillage system. While treatments where at least 25% of RDN has been substituted with FYM or biofertilizer under zero tillage system registered 106.3% and 87.6% increase respectively, compared to conventional tillage system (Table 4). The 2- irrigation and 5- irrigation has been slightly less favorable for enzyme activity as it resulted in a decrease of DH activity by 23.3% and 8.2%, respectively, compared to 3-irrigation. In contrast, the treatments where urea has been used as sole N-source (T_1) or where 75% urea+25% FYM (T_2) is applied, DH activity is found to be lower in case of 3-irrigation as compared to 2- irrigation and 5- irrigation. Similar, results have been obtained under remaining organic treatments where 3- irrigations brought about better DH activities than 2- irrigation and 5- irrigations.

The most important parameter influencing the soil DH activity has been tillage regime. However, the treatment where the sole organic source has been used as N-source along with 3- irrigation provide better results as compared to other nutrient treatments and irrigation regimes respectively. Here some variations are obtained for 2- irrigation and 5- irrigation regimes, where 75% urea+25% FYM treatment yielded slightly better results than sole organic N-source.

Soil Microbial Biomass Carbon

The zero tillage soil supported higher (104%) soil microbial biomass carbon (SMBC) than the conventional tillage soil (Table 2). The soils subjected to the 3- irrigation has shown the 12.14% and 27.17% higher SMBC than the 2-irrigation and 5- irrigation treatments, respectively. Significant variations in SMBC were recorded among different INM treatments as highest SMBC recorded in treatment T_6 followed by T_5 and then T_2. Application of RDN as organic sources has resulted in an increase of SMBC by 71.3% and 48.12% compared to control and RDN (as urea), respectively. However, Treatment T_3 & T_4 have produced little effect in improving SMBC under zero tillage wheat soils. This may be due to the low redox conditions existing under zero tillage soils. The partial or complete substitution of the RDN by organic sources favored SMBC significantly in zero tillage soils compared to conventional tillage soil. The magnitude of increase recorded under conventional tillage soil with sole organic source (123.34%), sewage sludge (111.54%), FYM (103.07%), GM (95.99%), and biofertilizer (92.9%) compared to the corresponding conventional tillage treatments (Table 5).

For a given N management treatment, the irrigation treatments played a significant role in determining SMBC status. The sole organic source substitution has shown the highest (333.18 mg C g^{-1} soil) (Table 5) SMBC at 3- irrigation. The 3- irrigation as a whole has shown highest SMBC values under all treatments applied followed by 2- irrigation and then 5- irrigation. Thus among the three different water regimes 3-irrigation supported significantly higher SMBC than 2-irrigation and 5- irrigation. The magnitude of decrease has been 10.37% and 14.79% for RDN through urea, 8.39% and 13.1% for RDN as FYM, 5.6% and 10.78% for RDN as GM, 22.56% and 56.19% for RDN as biofertilizer, 12.14% and 27.17% for sole organic N source, 2.57% and 17.12% for sewage- sludge and 6.19% and 22.35% for blank plot for 2- irrigation and 5-irrigation, respectively compared to 3- irrigation.

The most important parameter influencing the SMBC activity is tillage regime. However, the treatment where the sole organic source has been used as N-source along with optimum irrigation provide better results as compared to other nutrient treatments and irrigation regimes respectively.

Table 2. Effects of tillage, water regimes and integrated N management practices on soil biological properties in wheat cultivated under the contrasting agronomic practices.

Treatments	Soil respiration (mg CO_2 (100g)$^{-1}$ soil per h^{-1})	Soil dehydrogenase activity (μg TPF g^{-1} soil per h^{-1})	Microbial biomass carbon (μg g^{-1}soil)
Tillage (T)			
Conservation tillage	36.60	2.07	163.67
Conventional tillage	20.21	1.30	80.23
C.D. (0.05)	0.85	0.09	1.69
Water management (WM)			
2-irrigation (Sub-optimal)	27.32	1.50	121.82
3-irrigation (Optimum)	30.96	1.85	136.61
5-irrigation (Supra-optimum)	26.95	1.71	107.42
C.D. (0.05)	1.04	0.11	2.08
Tillage × WM (T ×WM)	*	*	*
INM			
1. Control	25.52	1.175	99.76
2. RDN through urea	30.96	1.955	115.41
3. 75% RDN through urea + 25% RDN through farmyard manure (FYM)	30.62	1.96	129.76
4. 75% RDN through urea + 25% RDN through green manure (GM)	25.86	1.33	107.82
5. 75% RDN through urea + 25%through Biofertilizer	32.22	2.10	146.49
6. 75% RDN through urea + 25%RDN through sewage sludge	25.19	1.31	108.01
7. 50% RDN as FYM + 25%RDN through biofertilizer + 25%RDN through green manure	32.72	2.144	170.95
8. Blank plot	24.21	1.191	97.32
CD (0.05)			
T × INM	*	*	*
WM × INM	*	*	*
T ×WM × INM	*	*	*

RDN, Recommended dose of nitrogen; *significant; values of conservation & conventional tillage are mean of respective tillage values, irrespective of water & nutrient treatments. Similarly, values for water management & nutrient management are mean of respective parameters of the other two. CD represents critical differences. Values are statistically significant. Data analyzed by one way ANOVA at LSD<0.05.

Table 3. Interaction of tillage, water regimes and integrated nutrient nitrogen management on soil respiration (mg CO_2 (100g)$^{-1}$ soil per 24 h^{-1}) in wheat cultivated under contrasting agronomic practices.

	Tillage							
	Conservation Tillage				Conventional Tillage			
	Water Regime							
Treatments	**2-irrigation (sub-optimal)**	**3-irrigation (optimum)**	**5-irrigation (supra-optimal)**	**Mean**	**2-irrigation (sub-optimal)**	**3-irrigation (optimum)**	**5-irrigation (supra-optimal)**	**Mean**
Control	33.220	34.760	30.300	32.76	18.410	19.210	17.220	18.28
RDN through urea	34.047	47.280	35.740	39.02	20.327	22.270	26.110	22.90
75% RDN through urea +25% RDN through farmyard manure (FYM)	40.700	42.020	36.120	39.61	22.340	24.140	18.380	21.62
75% RDN through urea + 25% RDN through green manure (GM)	31.580	34.100	31.860	32.51	19.240	21.110	17.260	19.20
75% RDN through urea + 25% through biofertilizer	35.227	47.080	40.760	41.02	20.680	26.840	22.700	23.41
75% RDN through urea + 25% RDN through sewage sludge	31.260	33.380	31.900	32.18	17.080	22.040	15.440	18.19
50% RDN as FYM + 25% RDN through biofertilizer + 25% RDN through green manure	43.900	48.430	39.160	43.83	24.700	21.123	19.020	21.61
Blank Plot	28.687	34.540	32.620	31.95	15.710	17.100	16.560	16.46
Mean	34.83	40.19	34.80		19.81	21.73	19.09	

C.D. (0.05)

1. Tillage × Water Regime = 0.073
2. Tillage × Nutrient Management = 0.120
3. Tillage × Nutrient Management = 0.140

Here RDN- Recommended Dose of Nitrogen, C.D. denotes Critical Difference, FYM- Farm Yard Manure, and GM- Green Manure Values are mean of the data (n = 6) and are statistically significant at $p<0.05$. Data analyzed by one way ANOVA at LSD<0

Table 4. Interaction of tillage, water regimes and integrated nutrient nitrogen management on soil dehydrogenase activity (µg g^{-1} soil per h^{-1}) in wheat cultivated under contrasting agronomic practices.

	Tillage							
	Conservation Tillage				**Conventional Tillage**			
	Water Regime							
Treatments	**2-irrigation (sub-optimal)**	**3-irrigation (optimum)**	**5-irrigation (supra-optimal)**	**Mean**	**2-irrigation (sub-optimal)**	**3-irrigation (optimum)**	**5-irrigation (supra-optimal)**	**Mean**
Control	1.230	1.320	1.240	1.26	1.023	1.133	1.143	1.090
RDN through urea	2.660	2.363	2.563	2.53	1.233	1.343	1.570	1.380
75% RDN through urea +25% RDN through farmyard manure (FYM)	2.770	2.467	2.690	2.64	1.350	1.123	1.370	1.280
75% RDN through urea + 25% RDN through green manure (GM)	1.280	1.643	1.120	1.35	1.113	1.113	1.703	1.310
75% RDN through urea + 25% through biofertilizer	2.317	3.423	2.470	2.74	1.110	1.313	1.963	1.460
75% RDN through urea + 25% RDN through sewage sludge	1.393	1.547	1.470	1.47	1.003	1.210	1.223	1.150
50% RDN as FYM + 25% RDN through biofertilizer + 25% RDN through green manure	2.350	3.460	2.377	2.729	1.137	1.660	1.870	1.560
Blank plot	1.030	1.330	1.347	1.240	0.963	1.240	1.243	1.195
Mean	1.880	2.430	1.910		1.120	1.270	1.510	
C.D. (0.05)	1.	Tillage × Water Regime =		0.16				
	2.	Tillage × Nutrient Management =		0.26				
	3.	Tillage × Nutrient Management =		0.32				

Here RDN- Recommended Dose of Nitrogen, C.D. denotes Critical Difference, FYM- Farm Yard Manure, and GM- Green Manure Values are mean of the data (n = 6) and are statistically significant at $p<0.05$. Data analyzed by one way ANOVA at LSD<0.05.

Table 5. Interaction of tillage, water regimes and integrated nutrient nitrogen management on soil microbial biomass carbon (SMBC) (µg g^{-1} soil per 24 h^{-1}) in wheat cultivated under contrasting agronomic practices.

	Tillage							
	Conservation Tillage				**Conventional Tillage**			
	Water Regime							
Treatments	**2-irrigation (sub-optimal)**	**3-irrigation (optimum)**	**5-irrigation (supra-optimal)**	**Mean**	**2-irrigation (sub-optimal)**	**3-irrigation (optimum)**	**5-irrigation (supra-optimal)**	**Mean**
Control	130.440	139.310	122.220	130.66	66.620	76.670	63.330	68.81
RDN through urea	152.630	168.470	146.760	185.95	72.910	80.140	71.570	74.87
75% RDN through urea +25% RDN through farmyard manure (FYM)	171.470	185.860	164.330	173.89	93.360	85.110	78.410	88.63
75% RDN through urea + 25% RDN through green manure (GM)	142.330	150.330	135.690	142.78	75.110	69.270	74.170	72.85
75% RDN through urea + 25% through biofertilizer	192.300	235.690	150.890	192.96	110.980	103.890	85.220	100.03
75% RDN through urea + 25% RDN through sewage sludge	151.660	155.560	132.817	146.68	70.430	74.150	63.430	69.34
50% RDN as FYM + 25% RDN through biofertilizer + 25% RDN through green manure	201.670	335.180	171.690	236.16	121.690	113.780	81.760	105.74
Blank plot	133.410	141.670	115.790	130.29	62.220	70.640	60.210	64.36
Mean	159.480	189.010	142.520		84.160	84.210	72.330	
C.D. (0.05)	1. Tillage × Water Regime = 2.94							
	2. Tillage × Nutrient Management = 4.81							
	3. Tillage × Nutrient Management = 5.88							

Here RDN- Recommended Dose of Nitrogen, C.D. denotes Critical Difference, FYM- Farm Yard Manure, and GM- Green Manure Values are mean of the data (n = 6) and are statistically significant at $p<0.05$. Data analyzed by one way ANOVA at LSD<0.05.

DISCUSSION

The data presented in table 2 to 5 indicate that the conservation tillage (i.e. zero/no-tillage) increases soil microbial activity in terms of soil respiration, soil DH and SMBC. The soil microbial activities have shown a positive synergistic effect of conservation tillage with 3- irrigation (at the gap of 20 days) for the wheat cultivation. Various nutrient treatments (i.e. inorganic form as well as organic form) also affect the soil microbial properties in tillage and irrigation treatments (34).

Higher soil microbial activities are indicative of enhanced soil fertility. It has been reported in many crop fields in various agro-climatic conditions during the conservation tillage (38). Masto et.al., 2006 (23) and Sahrawat et.al., 2010 (31) have reported that the increased microbial activity. The increased microbial activity enhance crop productivity and yield as well as better soil fertility in different agro-climatic conditions under conservation tillage system in wheat field.\

Daughtry et al. (5), reported increased biodegradation of biomass under conservation tillage in wheat fields. Martinez et al. (22) reported improved long-term soil microbial community and enzymatic activity responses to an integrated cropping and livestock system. However, no report is available to our data base which has reported high microbial activity in wheat fields in IGP under tillage management, various water regimes and different INM practices which include various organic supplements.

The excessive water, on the other hand can harm soil microbes and plant growth. It produces anaerobic conditions in rhizosphere and produces conditions like hypoxia (a condition of oxygen deficiency). The hypoxic condition inhibits reproductive growth of plants and thus delays harvest time. This condition reduces yield of plant to almost zero (13). Wheat suffers badly, if excessive amount of water is available to the plant rhizosphere (30). Therefore, it is essential to optimize water requirements for higher microbial activity, which may further lead to the improved soil fertility and the crop productivity.

The Irrigation regimes have also significantly affected microbial activities of rhizosphere (34). Our results indicate that 3-irrigations (each after 20 days) is sufficient to maintain higher soil microbial activity. But an increase in frequency of irrigation causes reduction in soil microbial activity. Thus, a double loss of crop yield and water (under excessive irrigation) occurs. Simultaneously, reduced irrigation (i.e. 2-irrigations) also causes a slight drop in values of soil microbiological parameters (Table 2 to 5).

Davis et al. (6), have reported that soil microbial communities play an important role in agroecosystem functioning on a large scale and they also contribute to global element cycling. The rhizosphere of plants contributes significantly to biogeochemical cycles (circulation of elements like C, N, P, S etc.) in biosphere. Biogeochemical cycles are important for maintaining ecological balance and nutrient availability (24). It has been observed that no-tillage practices increases availability of soil enzymes like acid phosphatase, amylase, cellulase etc. Thus, no-tillage practices help in circulation of minerals which enhances total carbon (C) and N availability to plants (2). Our results also support that increased microbial activity and thus improved nutrient availability help in circulation of minerals (table 4 and 5).

Indian soil of IGP region which is used for extensive agricultural practices are deficient in N. Therefore, the plants especially cereals like wheat are highly responsive to the exogenously supplied N-fertilizers (28). The excessive N-loading in extensive agricultural practices enhances the input cost of agriculture on one hand and causes nutrient losses in the form of leaching, run-off and volatilization (33, 35). It has been considered opinion that inorganic N-fertilizers should be replaced by organic forms e.g., FYM, GMs and biofertilizers etc. by maintaining the crop productivity as much as possible. This approach is considered as INM (31).

It indicate that INM practices, specially, replacement or substitution of inorganic sources with organic sources, (where 25-50% recommended dose of urea has been replaced by organic manures like FYM, biofertilizer (Azospirillium) and green manures) maintain highest soil respiration, soil DH and SMBC (Table 2 to 5) during wheat cultivation. Similar results have been reported by Hossain M.A., 2009 (14) and singh et.al., 2008 (34) in various cereals. However, studies are very rare in which the soil microbial activities under different N-nutrition including wheat have been correlated to water regimes and tillage practices, especially in IGP region.

CONCLUSIONS

The studies presented in this paper suggest that higher soil fertility in terms of soil microbial activity can be maintained in IGP having pre-dominantly the rice-wheat cropping system by using zero tillage as conservation tillage practice, optimal irrigation i.e. 3-irrigation at interval of 20 days. Further, either sole organic (FYM: Biofertilizer: GM (2:1:1)) or a combination of organic and inorganic N-applications in ratio of 1:1 can be used with above stated tillage and irrigation practices to save energy, water, cost of cultivation and to maintain high productivity of crops in an ecologically balanced manner.

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