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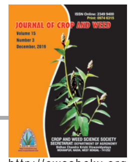

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Effect of soil moisture regimes and sources of nutrients on carbon sequestration potential in rice-wheat cropping system

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ABSTRACT

A field experiment was conducted to study the effect of soil moisture regimes and sources of nutrients on carbon sequestration potential in rice-wheat cropping system on a silty clay loam soil. Results revealed that grain yield and straw yield of rice and wheat, organic carbon sequestered in plant parts, microbial biomass carbon and soil organic carbon were increased with soil moisture regimes and nutrient management practices. Irrigated condition significantly increased the grain yield and straw yield of both rice and wheat over rainfed condition. Among nutrient management practices, organic nutrient management practice produced 55.4 and 48.2 per cent higher grain yield than inorganic nutrient management in rice and wheat crops, respectively. Under irrigated condition, rice-wheat cropping system produced significantly highest biomass and sequestered carbon. Organic nutrient management resulted in 50.3 and 51.8 per cent higher biomass and sequestered carbon, respectively in comparison to inorganic nutrient management.

Keywords: Carbon sequestration, inorganic, INM, irrigated, organic, rainfed, rice and wheat

Increase in the atmospheric concentrations of carbon dioxide (CO_2), the most abundant anthropogenic green house gas in the atmosphere, has resulted in global warming and climate change during the past centuries (IPCC, 2007). Carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric CO_2 or other forms of carbon to either mitigate global warming or avoid dangerous climate change (Roger and Brent, 2012). Soil carbon is a major component of the terrestrial carbon cycle - major reservoir and an important sink. The carbon sequestration potential of any soil depends on organic matter present in soil, cropping systems and microbial population in soil which contributes into its capacity to store resistant plant components in the medium term and to protect and accumulate the humic substances formed from the transformations or organic materials in the soil environment. The sequestration potential also depends on the chemical characteristics of the soil.

Organic agriculture offers a unique combination of environmentally-sound practices with low external inputs while contributing to food availability (Zundel, 2007). Organic farming emerged as a potential alternative for meeting food demand, maintaining soil fertility and increasing soil carbon pool. In developed countries, there is a steadily growing market for organic products, driven by the rising consumer awareness for health and environment which offers farmers a chance to produce for premium price markets and hence, an opportunity to increase their farm profitability and livelihoods.

Rice-wheat cropping system is the predominant and most profitable cropping system and emerges as the major cropping system in the Indo-Gangetic plains leading to the Green Revolution; Punjab, Haryana, Western Uttar Pradesh crescent has been the heart land of the Green Revolution. Wet land rice culture thus destroys soil structure and creates a poor physical condition for the following wheat crop. This soil condition can reduce wheat yield presumably by limiting root growth and distribution. For regeneration and maintenance of soil structure within this cropping system, plant residue is very important, but for various reasons, the amount of residue being returned to the soil is not adequate.

There is a need to compare the effect of different farming practices on the total carbon stored in a cropping system. A key feature of rice-wheat cropping system is the annual conversion of soil from aerobic to anaerobic and then back to aerobic conditions. Despite being a major domain of global food supply, rice-wheat cropping system is questioned for its contribution to carbon flux. Enhancing the organic carbon pool in this system is therefore, necessary to reduce environmental degradation and maintain agricultural productivity. Therefore, an experiment was conducted to study the response of soil moisture regimes and sources of nutrients on carbon sequestration potential in rice-wheat cropping system.

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MATERIALS AND METHODS

The field experiment was conducted for two seasons from *Kharif* (rice) of 2016 to *Rabi* (wheat) 2016-2017 at Model Organic Farm, Department of Organic Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya situated at 32°4' N latitude, 76°3'E longitude at an altitude of 1224 m above mean sea level. The area receives a high rainfall that ranges between 1500-2500 mm per annum, of which 80 per cent is received during monsoon months from June to September. The soil of the experimental site was silty clay loam in texture, acidic in reaction and high in organic carbon. The experiment was laid out in split plot design with soil moisture regimes in main plot and nutrient management in sub plot using three replications. The experiment consisted of 2 soil moisture regimes, *i.e.* irrigated and rainfed in main plots and 8 treatments comprising of combinations of 4 nutrient management practices, *i.e.* organic [(Vermicompost (VC)10 t ha^{-1} + Jeevamrit (3 drenchings: one before sowing and two after sowing at one month interval)], inorganic (recommended NPK), integrated (50% VC and 50% recommended NPK) and farmer's practice (25% VC + 25% recommended NPK) in sub plots. The present experiment was conducted in permanent plots of rice - wheat cropping system since *Kharif* 2014. Organically produced seeds of RP 2421 of rice and HPW-368 variety of wheat were procured for sowing from Department of Organic Agriculture & Natural Farming CSK HPKV Palampur. Rice seedlings was transplanted at 20 × 15 cm crop geometry under irrigated conditions only by using seed rate of 30 kg ha^{-1} whereas, under rainfed conditions rice was sown by using seed rate of 100 kg ha^{-1} at row spacing of 25 cm. Wheat was sown keeping row distance of 22.5 cm with seed rate of 100 kg ha^{-1}. In rice, the recommended dose of NPK used was 60 kg N, 30 kg P_2O_5 and 30 kg K_2O ha^{-1} in rainfed condition and 90 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1} in irrigated condition, whereas in wheat, the recommended dose of NPK used was 80 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1} in rainfed condition and 120 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1} in irrigated condition, respectively. In case of rice, remaining half dose of nitrogen was top dressed 2 times (first at 3 weeks interval from transplanting) while in wheat, half dose of nitrogen and whole P_2O_5 and K_2O were incorporated in soil, as per the treatments, as basal dose and remaining half dose of nitrogen was top dressed at tillering stage of the wheat crop. Nutrient content of vermicompost used was 1.5% N, 1.0% P and 0.6% K. After one month of sowing of seed, two drenchings of jeevamrit were applied at an interval of 30 days respectively. Foliar application of liquid manure vermiwash was done after dilution (1:10) with water at 30 days interval in both rice and wheat as per recommended cultivation guidelines of Department of Organic Agriculture and Natural Farming. Organic carbon in soil was determined by a standard method *i.e.* SOC × Soil depth × Bulk density. Microbial biomass carbon was determined by fumigation-extraction method of Vance *et al*. (1987). Carbon sequestration in plants was determined by following (IPCC, 2006) *i.e.,* total dry biomass of crop × 0.5

Total biomass produced under paddy-wheat cropping system (above ground plant biomass) = Grain yield of paddy + Straw yield paddy + Grain yield of wheat + Straw yield of wheat

Total carbon sequestered in the system = Carbon sequestered in the above ground plant parts + Carbon sequestered in the below ground plant parts + Total soil organic carbon + Microbial biomass carbon

RESULTS AND DISCUSSION

Yield of rice and wheat

Irrigated condition resulted in significantly higher rice yield (2593 kg ha^{-1}) in comparison to rainfed condition. The increase in yield was 32.8 per cent over rainfed condition. Among nutrient management treatments, organic nutrient management produced significantly highest yield which was statistically at par with integrated nutrient management and was 55.4per cent higher than the grain yield under inorganic treatment. Increased yield with organic nutrient management might be due to the enhanced biological processes by microbes in plant and soil enzymatic activity which affected the yield contributing characters of rice and hence, resulted in higher yield. Farmer's practice was proved to be significantly better than inorganic treatment in terms of grain yield which may be due to application of farm yard manure by the farmer.

Irrigated condition significantly increased the straw yield of rice. The increase was 31.8% over rainfed condition. Straw yield was significantly affected by different nutrient management practices and was highest in case of organic followed by integrated treatment and farmer's practice. Significantly least straw yield was obtained under inorganic nutrient management practice. Balamurugan and Sudhakar (2012) reported that among the various vermicompost treatments, grain yield and straw yield was increased in pressmud based vermicompost applied plots.

Table 1: Effect of treatments on grain and straw yield (kg ha^{-1}) of rice and wheat

Treatments	Rice		Wheat		Total above-ground biomass
	Grain yield	Straw yield	Grain yield	Straw yield	
Soil moisture regime					
Rainfed	1950	3393	1802	1794	8939
Irrigated	2593	4471	2549	2889	12502
SEm (±)	**81**	**117**	**51**	**134**	**226**
LSD (0.05)	**243**	**353**	**153**	**404**	**679**
Nutrient management					
Inorganic	1774	3044	1694	1922	8434
Integrated	2517	4378	2255	2494	11644
Farmer's practice	2037	3582	2244	2263	10126
Organic	2757	4724	2510	2687	12678
SEm (±)	**115**	**166**	**72**	**64**	**320**
LSD (0.05)	**345**	**500**	**217**	**NS**	**960**

Irrigated condition produced significantly higher grain yield of wheat (41.4%) than rainfed condition. While in case of nutrient management, organic nutrient management produced significantly high grain yield followed by integrated and farmer's practice which were statistically at par with each other. Significantly least yield was obtained from inorganic nutrient management practice. The results are in conformity with those of Seth *et al*. (2019) who reported significantly higher grain yield and straw yield of wheat under irrigated condition and also with integrated nutrient management in comparison to rainfed and inorganic treatment, respectively.

Total above ground biomass produced under rice-wheat cropping system was significantly affected by moisture conditions of the fields. It was 39.8% higher under irrigated condition in comparison to rainfed condition. Among nutrient management, organic treatment resulted in significantly highest biomass which was 50.3% higher than inorganic nutrient management. Similar results have been reported by Shah *et al.* (2011) while assessing the relationship of green manure legumes grown in the gap between wheat harvest and rice planting for sustainable rice-wheat system.

Interaction effect

The interaction effect between soil moisture regimes and nutrient management practices was non-significant in respect of grain yield and straw yield of rice and wheat.

Table 2: Interaction effect of treatments on grain yield and straw yield (kg ha^{-1}) of rice

Treatments	Inorganic	Integrated	Farmer's practice	Organic	Mean
Grain yield (kg ha^{-1})					
Rainfed	1431	2100	1926	2443	1975
Irrigated	2118	2935	2149	3171	2593
Mean	1775	2518	2038	2807	
LSD (0.05) (A × B)			**NS**		
Straw yield (kg ha^{-1})					
Rainfed	2587	3723	3083	4179	3393
Irrigated	3501	5033	4082	5269	4471
Mean	3044	4378	3583	4724	
LSD (0.05) (A× B)			**NS**		

Table 3: Interaction effect of treatments on grain yield (kg ha^{-1}) of wheat

Treatments	Inorganic	Integrated	Farmer's practice	Organic	Mean
			Grain yield (kg ha^{-1})		
Rainfed	1482	1900	1776	2050	1802
Irrigated	1906	2610	2710	2970	2549
Mean	1694	2255	2244	2510	
LSD (0.05) (A× B)			**NS**		
			Straw yield (kg ha^{-1})		
Rainfed	1293	2061	1698	2128	1795
Irrigated	2553	2927	2829	3247	2889
Mean	1923	2949	2264	2688	
LSD (0.05) (A×B)			**NS**		

Organic carbon in plant parts

The total carbon sequestered in plants of rice was significantly higher under irrigated condition in comparison to the rainfed condition. Among nutrient management practices, organic and integrated treatments were observed to result in significantly highest carbon sequestration as compared to farmer's practice. Inorganic treatment recorded least carbon sequestered through plant parts. The results were in conformity with those of Chauhan *et al.* (2015) who studied carbon sequestration under poplar based agro forestry system with rice-wheat crops.

Table 4: Effect of treatments on carbon stored (kg ha^{-1}) in parts of rice and wheat plants

Treatments	Rice			Wheat		
	Above ground	Below ground	Total	Above ground	Below ground	Total
Soil moisture regime						
Rainfed	1700	97	1797	1655	75	1730
Irrigated	2222	111	2331	2410	380	2790
SEm (±)	**76**	**2**	**76**	**65**	**49**	**62**
LSD (0.05)	**230**	**8**	**230**	**200**	**150**	**180**
Nutrient management						
Inorganic	1400	100	1500	1630	160	1790
Integrated	2270	100	2380	2140	330	2470
Farmer's practice	1840	100	1940	2040	190	2230
Organic	2330	100	2440	2310	230	2540
SEm (±)	**110**	**2**	**107**	**96**	**33**	**87**
LSD (0.05)	**330**	**NS**	**320**	**290**	**NS**	**260**

The total carbon stored in wheat plants varied significantly with different nutrient management practices. Significantly highest organic carbon was stored in plants under organic nutrient management practice as compared to inorganic treatment and farmer's practice. However, it was statistically at par with integrated nutrient treatment. Inorganic treatment recorded significantly lowest carbon sequestered value. Zomer *et al.* (2017) also clearly concluded that adoption of any SOC enhancing management practice such as incorporation of organic manures etc. increases the soil carbon and which in turn enhance above and below ground biomass carbon on agricultural land.

Microbial biomass carbon

Microbial biomass carbon accumulation at 0-15and15-30cm was not significant with varied conditions of rainfed and irrigated in rice. In case of nutrient management, different treatments did not vary significantly at 0-15 cm soil depth. However, at 15-30 cm depth, microbial biomass carbon was significantly highest under organic nutrient management was at par with integrated treatment. Soil biomass carbon was significantly lowest in the farmer's practice treatment and was statistically at par with inorganic treatment.

Table 5: Effect of treatments on microbial biomass carbon (µg C g^{-1} soil) under rice and wheat

Treatments	Microbial biomass carbon			
	Rice		Wheat	
	0-15	15-30	0-15	15-30
Soil moisture regime				
Rainfed	2.36	1.83	1.64	2.04
Irrigated	1.92	2.00	2.09	2.42
SEm (±)	**0.13**	**0.10**	**0.12**	**0.09**
LSD (0.05)	**NS**	**NS**	**0.37**	**0.28**
Nutrient management				
Inorganic	1.73	1.62	1.34	1.76
Integrated	2.31	2.26	2.11	2.15
Farmer’s Practice	1.86	1.38	1.35	2.04
Organic	2.66	2.39	2.66	2.98
SEm (±)	**0.12**	**0.15**	**0.17**	**0.13**
LSD (0.05)	**NS**	**0.45**	**0.53**	**0.40**

Microbial biomass carbon was significantly higher under irrigated condition in comparison to rainfed condition at 0-15 cm and 15-30 cm in wheat. Organic nutrient management resulted in significantly highest biomass carbon. It was 98.5 and 69.3% higher than inorganic treatment at 0-15 cm and 15-30 cm soil depths, respectively.

Soil organic carbon

Total soil organic carbon sequestered upto 30 cm of soil depth in rice fields under irrigated condition was significantly higher than rainfed condition. Among nutrient management practices, significantly highest organic carbon was recorded in organic treatment followed by integrated treatment which was statistically at par with farmer’s practice treatment. The results are in confirmatory with those of Kanwar *et al.* (2002) who reported that organic carbon content was higher in the plots which received organic manures (vermicompost and FYM) alone than the plots which received NPK fertilizers only.

Table 6: Effect of treatments on soil organic carbon stored in soil (kg ha^{-1}) under rice

Treatments	Rice			Wheat		
	Soil organic carbon		Total soil organic	Soil organic carbon		Total soil organic
Soil depth (cm)	0-15	15-30	carbon stored	0-15	15-30	carbon stored
Soil moisture regime						
Rainfed	5.7	14.0	19.7	195.0	339.3	894.0
Irrigated	16.0	21.0	37.0	259.3	447	1250.3
SEm (±)	**0.2**	**0.3**	**0.4**	**8.1**	**11.7**	**22.6**
LSD (0.05)	**0.8**	**0.9**	**1.2**	**24.3**	**35.3**	**67.9**
Nutrient management						
Inorganic	7.2	15.0	22.2	177.4	304.4	843.5
Integrated	10.0	17.0	27.0	251.7	437.8	1164.5
Farmer’s practice	10.4	16.0	26.4	203.7	358.2	1012.8
Organic	15.7	20.0	35.7	275.7	472.4	1267.9
SEm (±)	**0.4**	**0.4**	**0.5**	**11.5**	**16.6**	**32.0**
LSD (0.05)	**1.2**	**1.3**	**1.7**	**34.5**	**50.0**	**96.0**

Total soil organic carbon sequestered under irrigated condition was significantly higher than rainfed condition in wheat. In case of nutrient management, total soil organic carbon stored in the soil was significantly highest in organic treatment followed by integrated nutrient treatment. Inorganic treatment was observed to be statistically at par with the farmer's practice. The results are corroborated with the findings of Mann *et al*. (2006). The continuous growing of maize-wheat cowpea cropping sequence, over the years with integrated use of inorganic fertilizers and FYM markedly increased organic carbon content of soil over control.

Total carbon sequestered under rice-wheat cropping system

Total carbon sequestered under rice-wheat cropping system was significantly higher under irrigated condition in comparison to rainfed condition. The four nutrient management practices significantly affected the total carbon sequestered by the system. Carbon sequestered under organic treatment was significantly highest than farmer's practice and was at par with integrated nutrient management.

Table7: Effect of treatments on total carbon sequestered (kg ha^{-1}) under rice-wheat cropping system

Treatments	Rice		Wheat		Total carbon sequestered
	Plant	Soil	Plant	Soil	
Soil moisture regime					
Rainfed	1790	19	1720	11	3540
Irrigated	2330	37	2790	12	5160
SEm (±)	**596**	**40**	**60**	**26**	**90**
LSD (0.05)	**230**	**120**	**180**	**80**	**270**
Nutrient management					
Inorganic	1500	22	1790	10	3320
Integrated	2380	27	2470	12	4890
Farmer's practice	1940	26	2240	9	4220
Organic	2440	36	2550	14	5040
SEm (±)	**106**	**56**	**86**	**40**	**130**
LSD (0.05)	**320**	**170**	**260**	**120**	**390**

The study unveiled that irrigated condition and organic nutrient management resulted in higher carbon sequestration potential in rice-wheat system.

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