Impact of long term tillage and soil moisture regime on the sulphur, organic carbon, DOC, MBC and MBN of soil under mung bean-wheat and sorghum-wheat cropping system

Abstract

The field experiment entitled "Impact of long term tillage and soil moisture regime on the sulphur, organic carbon, DOC, MBC and MBN of soil under mung bean-wheat and sorghum-wheat cropping system" was conducted during 2021-22 on an on-going long term experiment which was started since 2006-07 at Soil Research Farm, Department of Soil Science, CCS HAU, Hisar. The field experiment consisted of three tillage treatments i.e. CT-CT (Conventional tillage in both *kharif* and *rabi* season), ZT-CT (Zero tillage in *kharif* and conventional tillage in *rabi*) and ZT-ZT (Zero tillage in both *kharif* and *rabi* season). The experiment also consisted of two cropping system MW and SW (Mung bean-wheat and sorghum-wheat) and three soil moisture regimes (IW/CPE= 0.60, 0.75 and 0.90) with three replications. The results of the experiments revealed that the sulphur, organic carbon, DOC, MBC and MBN content of the soil were higher under MW than SW cropping system. The highest mean value of sulphur, organic carbon, DOC, MBC and MBN was reported under ZT-ZT followed by ZT-CT and the lowest mean value was under CT-CT under both cropping system. Similarly, the soil moisture regime $M_{0.90}$ reported the highest mean value of available sulphur, organic carbon, DOC, MBC and MBN content followed by $M_{0.75}$ whereas the lowest mean value was under $M_{0.60}$ under both the cropping system.

Keywords: zero tillage, cropping system, DOC, MBC, organic carbon, etc.

INTRODUCTION

Mechanical manipulation of soil to provide favourable condition for proper crop growth is called tillage. Soil tillage consists of breaking the compact surface of earth to a certain depth and to loosen the soil mass so as to enable the roots of the crops to penetrate and spread into the soil. The main objectives of the tillage is to prepare a desirable soil structure for a deep seed bed or a root bed suitable for different types of crops, to control weed and to minimize the soil erosion. Tillage that is deeper and more thorough is classified as primary, and tillage that is shallower and sometimes more selective of location is secondary. Primary tillage such as ploughing tends to produce a rough surface finish, whereas secondary tillage tends to produce a smoother surface finish, such as that required to make a good seedbed for many crops. Tillage has been the important part of agriculture history because it achieve many agronomic practices. But the excessive tillage practices affect soil health, crop productivity and environment quality by affecting soil carbon loss and emission of green house gases (Kahlon and Gurpreet, 2014). Therefore, to counteract all these constraints conservation agriculture has been promoted which enhance soil quality related to carbon sequestration that favour soil biology and physical condition (Bronick and Lal, 2005; Munoz *et al.*, 2007). Conservation agriculture promotes minimum soil disturbance, maintenance of permanent soil cover and diversification of plant species. Conservation agriculture is increasing worldwide due to its economical and environmental benefits for farmers, environment and society. Economic benefits may arise from lower drought susceptibility due to higher plant-available soil water content resulting in higher yield stability, the saving of labor and fuel and higher economic returns. Ecological benefits include the increase of soil organic carbon (SOC), biotic activity, soil porosity, agro-ecological diversity and less soil erosion and carbon emissions (Neugschwandtner *et al.,* 2014). Soil tillage influence the soil chemical characteristics, carbon sequestration and nutrients distributions. Similar to tillage, soil moisture is also an important parameter which affects the physical, chemical and biological properties of the soil. Soil water plays an important role in maintaining the optimum pH and salinity condition which is essential for plant growth (Chang *et al.,* 2019). Soil water contains nutrients that move into the plant roots when plants take in water. The mineralization and immobilization of nutrients in the soil was controlled by microbes which required an optimum soil moisture. Yang *et al.* (2018) reported that optimum water condition increase the soil microbial carbon, nitrogen, soil urease activity and soil translocase. Liu *et al.* (2015) also reported that adequate soil moisture increase the species and numbers of nitrogen fixing bacteria, gamma deformation bacteria and alpha deformation bacterial of the soil. Extreme moisture conditions would limit CO_2 release: low soil moisture would limit microbial and root respiration; excessive would block the soil pore and limit O_2 and CO_2 release. Generally, SOC mineralization rate increases with the soil water content (Yun *et al.,* 2019). The aim of this study was to influence the impact of long term tillage and soil moisture regime on the sulphur, organic carbon, DOC, MBC and MBC of the soil under mung bean-wheat and sorghum-wheat cropping system.

MATERIAL AND METHODS

Experiment site characteristics

The field experiment was conducted from the on-going experiment, which was started since 2006-07 at Soil Research Farm, Department of Soil Science, CCS HAU, Hisar. Hisar is the administrative headquarters of Hisar district in the state of Haryana in northwestern India. Hisar is located at 29.09°N 75.43°E in western Haryana. It has an average elevation of 215 m above mean sea level. The soil of the experimental site was sandy loam in texture, slightly alkaline, low in organic carbon, low in available nitrogen, medium in available phosphorus and high in available potassium (Phogat, 2019). The main characteristics of climate of experiment site are dryness, extremes of temperature, and scanty rainfall. The maximum daytime temperature during the summer varies between 40 and 46 °C. During winter, its ranges between 1.5 °C and 4 °C. Relative humidity varies from 5 to 100%. The average annual rainfall is around 429 mm, most of which occurs during July and August. Dew is observed in December and January. Hot winds, locally known as loo, are strong and frequent from May to July.

Treatments and experimental design

The experiment was carried out in two main plots treatments viz. (i) Mungbean-wheat and (ii) Sorghum-wheat cropping system. These main plots were split in to sub plots receiving three different tillage practices i.e (i) Conventional tillage in both *kharif* & *rabi* seasons (CT-CT), (ii) conventional tillage in *kharif* & zero tillage in *rabi* seasons (CT-ZT) and, (iii) zero tillage in both *kharif* & *rabi* seasons (ZT-ZT). These sub-plots were further split into sub-sub plots receiving different soil moisture regimes viz. IW/CPE =0.60, 0.75 and 0.90 to each sub-plots. The experiment was layout in split plot design and size of each plot was 35m x 8m. Replications were three of each treatments and in conventional tillage field was ploughed during both the season. In second treatment plots, the fields were ploughed during *kharif* only and no tillage was done during *rabi* season. In zero tillage plots, no tillage was done during both the seasons. The residues of the preceding crop were removed in conventional tillage. In zero tillage practice plots, the crop was harvested and no tillage was done for preparation of seed bed for the succeeding crop, and zero till machine was used for sowing the crop.

Soil sampling and measurement

The soil samples were collected from 0-15 cm depth after the harvest of the crop in the end of the *kharif* season. Three samples from each of the plots were collected with the help of augur and khurpi and made a composite sample by mixing these samples. These composite sample were brought to the laboratory in the sampling bag, dried in shade, grind, sieved (2mm) and finally stored in the sampling bag with proper labeling. Available sulphur was determined was estimated turbidimetric method developed by Chesnin and Yien, 1950. Dissolved organic carbon was determined by dichromate acid oxidation method (Ciavitta *et al.*, 1989). Total soil organic carbon was determined using Walkley and Black (1934) wet digestion method. Microbial biomass carbon was determined by the chloroform ($CHCl_3$) fumigation method proposed by Vance *et al*., (1987). Microbial biomass nitrogen in soil samples was estimated as per the method of Brookes *et. al.* (1985).

STATISTICAL ANALYSIS

The data generated in both laboratory and field experiments were statistical analysed as per the design of experiment. Treatment effects were compared with CD (0.05). Statstical analysis was done in consultation with Department of Mathematics and Statistics, CCS Haryana Agricultural University, Hisar.

RESULTS

Available sulphur

The sulphur content under mung bean-wheat cropping system was significantly higher than sorghum-wheat (Table. 1). The effect of tillage practices on available sulphur was significant and highest mean value of available sulphur was 28.00 and 20.44 kg ha^{-1} under ZT-ZT. The available sulphur in this treatment was statistically at par with ZT-CT and significantly different from CT-CT in mung bean-wheat cropping system but in sorghum-wheat cropping system it was statistically at par with both CT-CT and ZT-ZT treatment. Also, the sulphur content under ZT-CT treatment had mean value of 26.87 and 19.86 kg ha^{-1} which was also statistically at par with CT-CT treatment. The lowest value of available sulphur was 24.99 and 18.58 kg ha^{-1} under CT-CT treatment. The effect of soil moisture regimes was found significant on available sulphur under both cropping system. The highest mean value of available sulphur was 29.47 and 20.44 kg ha^{-1} under soil moisture regime $M_{0.90}$ which was significantly higher than $M_{0.75}$ and $M_{0.60}$. Similarly, the mean value of available sulphur under $M_{0.75}$ was 26.28 and 19.65 kg ha^{-1} which was significantly higher than $M_{0.60}$. The lowest mean value of available sulphur was 25.12 and 18.79 kg ha^{-1} in the plots under $M_{0.60}$. However, the combine effect of cropping system and tillage; cropping system and soil moisture regimes; tillage and soil moisture regimes; cropping system, tillage and soil moisture regimes on available sulphur was found non-significant.

Dissolved organic carbon (DOC)

The DOC was found significantly higher under sorghum-wheat cropping system then mung bean-wheat (Table. 2). The highest DOC mean value (0.54 and 0.48 g kg^{-1}) under both cropping system was recorded under ZT-ZT treatment and lowest (0.49 and 0.41 g kg^{-1}) was under CT-CT treatment. The mean value of DOC under ZT-ZT was found significantly higher than ZT-CT and CT-CT under both cropping system. Also, the mean value of DOC under the ZT-CT tillage treatment was 0.52 and 0.44 g kg^{-1} which was also significantly higher than the CT-CT treatment. Present study revealed that the DOC content of the plots under different soil moisture regime was also significantly affected and increased as the soil moisture regimes increased. The highest mean value of DOC was 0.54 and 0.47 g ka^{-1} under $M_{0.90}$. This mean value of DOC was found significantly higher than the $M_{0.75}$ and $M_{0.60}$ under both cropping system. Similarly, the mean value of DOC (0.51 and 0.44 g kg^{-1}) which was under $M_{0.75}$ soil moisture regimes was also significantly higher than $M_{0.60}$. The lowest mean value of DOC was 0.50 and 0.42 g kg^{-1} under soil moisture regime $M_{0.60}$. However, the interactive effect of cropping system and tillage; cropping system and soil moisture regimes was found significant whereas tillage and soil moisture regimes; cropping system, tillage and soil moisture regimes was found non-significant.

Soil organic carbon

The organic carbon was reported significantly higher under mung bean-wheat than sorghum-wheat cropping system (Table. 3). However, the soil under ZT-ZT recorded highest (0.77 and 0.75 %) mean value of organic carbon which was significantly higher than ZT-CT and ZT-ZT under both cropping system. The lowest (0.69 and 0.67 %) mean value of organic carbon was observed under CT-CT under both cropping system. Also, the soil under ZT-CT mean value of organic carbon was 0.74 and 0.72 % under both cropping system respectively which was significantly higher than CT-CT. Similarly, long term effect of moisture regime also significantly effect the organic carbon of soil. It was observed that the organic carbon of soil increased as soil moisture regimes increased. The highest mean value of organic carbon was observed under under $M_{0.90}$ (0.76 and 0.74 %) under both system respectively. The organic carbon in the soil under $M_{0.90}$ was found significantly higher than $M_{0.75}$ and

$M_{0.60}$. Also, the soil under $M_{0.75}$ moisture regimes have mean value of soil organic carbon 0.73 and 0.71 % in both cropping system which was significantly higher than $M_{0.60}$ whereas the lowest mean value of soil organic carbon (0.71 and 0.69 %) was observed under $M_{0.60}$. However, the combined effect of cropping system and tillage; cropping system and soil moisture regimes; cropping system, tillage and soil moisture regimes was found non-significant.

Microbial biomass carbon (MBC)

The MBC of the soil was significantly affected by the cropping system and it was higher under mung bean-wheat cropping system as compared to sorghum-wheat (Table. 4). The mean MBC which was under ZT-ZT were 838 and 817 mg kg^{-1} which was found significantly higher than ZT-CT and CT-CT under both cropping system. Similarly, the mean MBC (761 and 738 mg kg^{-1}) under ZT-CT was also significantly higher than which was under CT-CT under both cropping system. The lowest mean value of MBC was 681 and 662 mg kg^{-1} which was reported under CT-CT tillage treatment under both cropping system. This data also show that the MBC was also significantly affected by the different soil moisture regimes. It was observed that the mean value of the MBC was increased as the soil moisture regime increased. The soil which was under $M_{0.90}$ gave the highest mean value of MBC (868 and 851 mg kg^{-1}) under both cropping system which was found significantly higher than the mean MBC of other two moisture regimes. The mean value of MBC which was under $M_{0.75}$ was 748 and 735 mg kg^{-1} under both the cropping system respectively. These mean value of MBC under $M_{0.75}$ soil moisture regimes was significantly higher than $M_{0.60}$ under both cropping system whereas the lowest (663 and 630 mg kg^{-1}) mean value of MBC was reported under $M_{0.60}$ soil moisture regime under both cropping system. The cropping pattern and tillage; cropping pattern and soil moisture regimes; tillage and soil moisture regimes; cropping pattern, tillage and soil moisture regimes also significantly effect the MBC of the soil. In both cropping system, the soil under ZT-ZT and $M_{0.90}$ had the highest value of MBC was 919 mg kg^{-1} which was significantly higher than rest of the treatment whereas the lowest (545 mg kg^{-1}) value was under CT-CT and $M_{0.60}$ which was also significantly lower than rest of the treatment.

Microbial biomass nitrogen

The MBN of the soil of plots was significantly affected by the cropping system and record higher in mung bean-wheat cropping system than sorghum-wheat (Table. 5). The highest mean value (135.7 and 121.6 mg kg^{-1}) of MBN was observed under ZT-ZT treatment followed by ZT-CT (106.3 and 96.1 mg kg^{-1}) under both the cropping system respectively. The mean value of MBN which was observed in the ZT-ZT was significantly higher than the other two tillage practices whereas ZT-CT was significantly higher than CT-CT under both cropping system. The lowest mean value of MBN was recorded in CT-CT tillage treatment which was 90.5 and 85.4 mg kg^{-1} under both the cropping system respectively. Present data revealed that the effect of different soil moisture regimes on the

MBN was found significant and was highest in the plots which was under $M_{0.90}$. It was reported that the mean value of MBN was increased as the value of soil moisture regime increased. The mean value of MBN which was under $M_{0.90}$ was 122.0 and 108.9 mg kg^{-1} under both cropping system which was found significantly higher than the other two soil moisture regimes. The soil which was under soil moisture regime $M_{0.75}$ had mean value of MBN 103.9 and 96.7 mg kg^{-1} which was significantly higher than $M_{0.60}$. The lowest mean value (87.4 and 83.7 mg kg^{-1}) of MBN was recorded in the plots which was under soil moisture regime $M_{0.60}$. Also, the interactive effect of cropping system and tillage; cropping system and soil moisture regimes; tillage and soil moisture regimes; cropping system, tillage and soil moisture regimes was observed significant on the microbial biomass nitrogen of the soil.In both cropping system, the soil under ZT-ZT and $M_{0.90}$ had the highest value of MBN was 135.7 mg kg^{-1} which was significantly higher than rest of the treatment whereas the lowest (71.0 mg kg^{-1}) value was under CT-CT and $M_{0.60}$ which was also significantly lower than rest of the treatment.

Table 1. Effect of moisture regimes and tillage on the available sulphur (kg ha^{-1}) of soil under mung bean-wheat and sorghum-wheat cropping system.

Moisture Regime (IW/CPE)	Mung bean-Wheat			Mean	Sorghum-Wheat			Mean
	ZT-ZT	ZT-CT	CT-CT		ZT-ZT	ZT-CT	CT-CT	
$M_{0.60}$	26.49	24.70	24.19	25.12	19.59	19.29	17.50	18.79
$M_{0.75}$	28.08	26.75	24.00	26.28	20.33	19.77	18.96	19.65
$M_{0.90}$	30.44	29.18	28.79	29.47	21.51	20.52	19.27	20.44
Mean	28.00	26.87	24.99		20.44	19.86	18.58	
CD (p=0.05)	A = 5.31, B = 1.95, C = 0.35, AXB = NS, AXC= NS, BXC= NS, AXBXC=NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table 2. Effect of moisture regimes and tillage on the DOC (g kg^{-1}) of soil under mung bean-wheat and sorghum-wheat cropping system.

Moisture Regime (IW/CPE)	Mung bean-Wheat			Mean	Sorghum-Wheat			Mean
	ZT-ZT	ZT-CT	CT-CT		ZT-ZT	ZT-CT	CT-CT	
$M_{0.60}$	0.52	0.51	0.48	0.50	0.45	0.41	0.39	0.42
$M_{0.75}$	0.54	0.50	0.49	0.51	0.49	0.43	0.41	0.44
$M_{0.90}$	0.57	0.54	0.51	0.54	0.51	0.48	0.44	0.47
Mean	0.54	0.52	0.49		0.48	0.44	0.41	
CD (p=0.05)	A = 0.017, B = 0.007, C = 0.009, AXB = 0.010, AXC= 0.012, BXC= NS, AXBXC=NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table 3. Effect of moisture regimes and tillage on the soil organic carbon (%) of soil under mung bean-wheat and sorghum-wheat cropping system.

Moisture Regime (IW/CPE)	Mung bean-Wheat			Mean	Sorghum-Wheat			Mean
	ZT-ZT	ZT-CT	CT-CT		ZT-ZT	ZT-CT	CT-CT	
$M_{0.60}$	0.74	0.71	0.68	0.71	0.72	0.68	0.64	0.69

$M_{0.75}$	0.77	0.74	0.69	0.73	0.75	0.71	0.67	0.71
$M_{0.90}$	0.79	0.77	0.71	0.76	0.77	0.74	0.70	0.74
Mean	0.77	0.74	0.69		0.75	0.72	0.67	
CD (p=0.05)	A = 0.010, B = 0.015, AXB = NS, C = 0.015, AXC= NS, BXC= NS, AXBXC=NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table 4. Effect of moisture regimes and tillage on the microbial biomass carbon (mg kg^{-1}) of soil under mung bean-wheat and sorghum-wheat cropping system.

Moisture Regime (IW/CPE)	Mung bean-Wheat			Mean	Sorghum-Wheat			Mean
	ZT-ZT	ZT-CT	CT-CT		ZT-ZT	ZT-CT	CT-CT	
$M_{0.60}$	748	672	570	663	713	633	545	630
$M_{0.75}$	847	736	662	748	835	728	643	735
$M_{0.90}$	919	874	811	868	903	855	797	851
Mean	838	761	681		817	738	662	
CD (p=0.05)	A = 0.16, B = 0.19, C = 0.16, AXB = 0.23, AXC= 0.21, BXC= 0.25, AXBXC=0.29							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table 5. Effect of moisture regimes and tillage on the microbial biomass nitrogen (mg kg^{-1}) of soil under mung bean-wheat and sorghum-wheat cropping system.

Moisture Regime (IW/CPE)	Mung bean-Wheat			Mean	Sorghum-Wheat			Mean
	ZT-ZT	ZT-CT	CT-CT		ZT-ZT	ZT-CT	CT-CT	
$M_{0.60}$	96.5	86.7	79.1	87.4	91.6	88.6	71.0	83.7
$M_{0.75}$	117.8	103.8	90.2	103.9	110.5	93.0	86.8	96.7
$M_{0.90}$	135.7	128.2	102.2	122.0	121.6	106.8	98.3	108.9
Mean	116.7	106.3	90.5		107.9	96.1	85.4	
CD (p=0.05)	A = 3.8, B = 1.9, C = 1.5, AXB = 2.6, AXC= 2.2, BXC= 2.7, AXBXC=3.8							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

DISCUSSION

Available sulphur

The available sulphur content of the soil under long term tillage treatment and soil moisture regimes was higher under zero tillage than conventional tillage under both the cropping system. The available sulphur content of the soil was significantly higher under mung bean-wheat cropping system than sorghum-wheat. The available sulphur content of the soil was highest under ZT-ZT followed by ZT-CT and lowest under CT-CT under both the cropping system. The higher mean value of available sulphur under zero tillage was might be due to higher organic matter which decompose and increase the available sulphur status of the soil. Alam *et al.* (2014) and Shiwakoti *et al.* (2019) reported higher content of available sulphur under zero tillage than conventional tillage. Also, the higher root mass and crop residue under zero tillage increase the sulphur mineralization microbes population which enhance the sulphur content of the soil. Increase in the microbial population under no tillage was also reported by He *et al.* (2007) and Srour *et al*. (2020) in their long term tillage experiments. In the present study, the available sulphur content in the plots increased as the soil moisture regimes increased under both the cropping system. The highest mean value of available sulphur was observed under $M_{0.90}$ followed by $M_{0.75}$ whereas the lowest mean value was under $M_{0.60}$ under both the cropping system. The increase in the availability of sulphur with increase in the moisture content of the soil may be due to high microbial activities and higher mineralization of organic sulphur which increase its availability. Hassan (2022) reported higher mineralization and higher sulphur content at higher soil moisture content. Enhancement in the enzyme and microbial activities with increase in soil moisture content reported by Chen *et al.* (2022) which enhance the mineralization of organic matter which increase the available sulphur content of soil.

Dissolved organic carbon (DOC)

The dissolved organic carbon content of the soil under long term tillage and soil moisture regimes was significantly higher under zero tillage than conventional tillage under both the cropping system. The dissolved carbon content of the soil was higher under mung bean-wheat cropping system than sorghum-wheat cropping system. The higher mean value of dissolved organic carbon under mung bean-wheat cropping system might be due to more crop residue and root biomass with low C:N ration which decompose easily and increases the carbon content. Higher dissolved organic carbon under legume based cropping system was reported by Li *et al.* (2023). The highest mean value of dissolved organic carbon was observed under ZT-ZT followed by ZT-CT and the lowest mean value was under CT-CT under both the cropping system. The higher value of dissolved organic carbon under zero tillage might be due to accumulation of more crop residue which increase the dissolved organic carbon of soil on decomposition. Increase in the dissolved organic carbon under no till was reported by Dou *et al.* (2008) and Schmidt and Martinez (2019). The dissolved organic carbon content of the soil increases with the increase in the soil moisture regimes under both cropping system. The highest mean value of dissolved organic carbon was observed under $M_{0.90}$ followed by $M_{0.75}$ whereas the lowest mean value was under $M_{0.60}$ under both cropping system. The increase in dissolve organic carbon in soil with increase in soil moisture might be due to higher microbial biomass which decompose the soil organic matter and enhance the carbon status of soil. The positive influence of soil moisture on the microbial biomass was reported by Curtin *et al.* (2012) and Bhanwaria *et al*. (2022). Yun *et al.* (2019) reported an increases in the dissolve organic carbon of the soil with increase in soil moisture.

Soil organic carbon

The organic carbon content of the soil was significantly higher under mung bean-wheat cropping system than sorghum-wheat which might be due to narrow C:N ratio of the legumes which decompose easily and increase the SOC content of the soil. Cogreves *et al.* (2015) also reported higher value of SOC under legumes crop under different cropping systems in their findings. The highest mean value of organic carbon was under ZT-ZT followed by ZT-CT whereas the lowest mean value was under CT-CT under both the cropping system. The value of organic carbon was significantly higher under ZT-ZT might be due to less disturbance of soil which increase the organic matter content as well as root mass of the soil. The lower value of organic carbon under CT-CT was due to fast oxidation of the organic matter of the soil which decrease the organic carbon of the soil. Kahlon and Gurpreet *et al.* (2014) and Neugschwandtner (2014) reported higher value of organic carbon of the soil under zero tillage as compared to conventional tillage in their field experiments. Also, under different soil moisture moisture regimes the organic carbon was highest under $M_{0.90}$ whereas the lowest value was under $M_{0.60}$ under both the cropping system. The increase in the soil organic carbon with increase in soil moisture regimes might be due to favourable conditions for the microbes to decompose the organic matter which increase the soil organic carbon. Yun *et al.* (2019), and Fang *et al.* (2022) also noticed an increase in the soil organic carbon with increase in the soil moisture content in their field experiments.

Microbial biomass carbon and nitrogen (MBC and MBN)

The microbial biomass carbon and nitrogen was significantly affected by the cropping system, tillage and soil moisture regimes. The microbial biomass carbon and nitrogen was higher in the soil which was under zero tillage as compared to conventional tillage. The microbial biomass carbon and nitrogen of the soil was higher under mung bean-wheat cropping system than sorghum-wheat cropping system. Higher microbial biomass carbon in the soil under legume based cropping system was reported by Li *et al.* (2023). The highest mean value of microbial biomass carbon and nitrogen was observed under ZT-ZT followed by ZT-CT and minimum was under CT-CT under both the cropping system. The higher mean value of microbial biomass under zero tillage may be due to more crop residue and less disturbance in the soil which increase the microbial population and provide a steady source of carbon to the microbes which enhanced the microbial biomass carbon and nitrogen of the soil. These results are similar to the findings of Balota *et al.* (2002), Bausenwein *et al.* (2008) and Yeboah *et al.* (2016) which indicated no tillage generally increase the microbial biomass carbon and nitrogen of soil. The microbial biomass carbon and nitrogen of the soil increase with increase in the soil moisture regimes under both the cropping system because high moisture create favourable condition for the microbial activity. Similar results are found by Bhanwaria *et al.* (2022) and Tuo *et al.* (2023).

CONCLUSION

The results of the present experiment concluded that the long term zero tillage and optimum soil moisture regimes improves the chemical properties of the soil as compared to conventional tillage under mung bean-wheat and sorghum-wheat cropping system. The results also show that the legume based cropping system is better than non-legume based cropping system. The results also concluded that long term zero tillage and optimum soil moisture regime increases the available sulphur, organic carbon, DOC, MBC and MBN of the soil as compared with conventional tillage under mung bean-wheat and sorghum-wheat cropping system.

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